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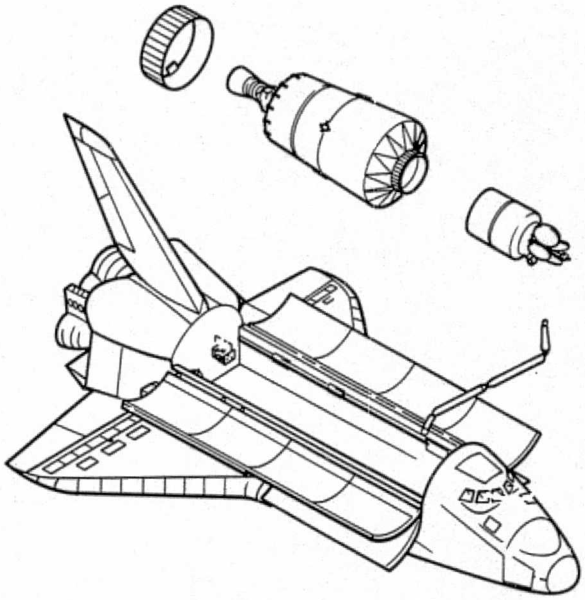

SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY

FINAL REPORT

VOLUME III ✦ TUG/PAYLOAD/ORBITER INTERFACE REQUIREMENTS

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GENERAL DYNAMICS
Convair Division

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SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY

FINAL REPORT

VOLUME III + TUG/PAYLOAD/ORBITER INTERFACE REQUIREMENTS

June 1975

Prepared for
National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

Prepared by
GENERAL DYNAMICS CONVAIR DIVISION
P.O. Box 80847
San Diego, California 92138

FOREWORD

The study described in this report was conducted by Convair Division of General Dynamics Corporation under NASA Contract NAS8-31012. The work was under the management of the NASA Marshall Space Flight Center, Tug Task Team, in conjunction with four complementary Tug-related study efforts.

The study was conducted between July 1974 and March 1975.

ACKNOWLEDGMENTS

Due to the broad scope of the interface compatibility study, many individuals were involved in providing technical assistance. General Dynamics Convair personnel who significantly contributed to the study include:

Ed Bock — Study Manager

Lee Browning — Structures/Dynamics

Jack Dyer
Wes Dreyer
Lee Siden

Jerry Nuding — Mechanisms

Joe Streetman — Fluids

Bob Eidson

Al Walburn — Environmental

Gordon Stone
Gordon Getline

Jack Fisher — Avionics

Wayne Groesbeck
Stan Maki
Bob Horsley

Norm Tipton — Safety

Bob Howe

Lee Bolt — Economic Analysis

Tom Tindel

Dick Parsons - Operations

Ken Nuss

Frank Jarlett — Programmatics

Ed Seiden
Carl Crone

NASA technical direction for the interface study was by:

Edward Stluka — Contracting officer's representative (COR)
Ralph Barnes — Assistant COR

SUMMARY

The Space Tug/Shuttle interface compatibility study was performed to identify, evaluate, and develop Tug plus payload-to-Orbiter accommodations requirements. The study was the instrument by which design changes to satisfy these requirements were submitted to NASA.

Previously performed Tug-related studies did not specifically address the use or suitability of Orbiter-supplied general-purpose payload support equipment or provide detail description of any Tug-dedicated peripheral equipment. The interface study investigated these areas and supplied the lacking data.

Shuttle interfaces required for Space Tug accommodation are primarily involved with supporting and servicing the Tug during launch countdown, flight, and postlanding; deploying and retrieving the Tug on orbit; and maintaining control over the Tug when it is in or near the Orbiter. Each of these interface areas was investigated during the study to determine the best physical and operational method of accomplishing the required functions, with an overriding goal of establishing simple and flexible Orbiter interface requirements suitable for Tug, Tug payloads, and other cargo.

The Space Tug/Shuttle interface compatibility study was arranged into six tasks that were accomplished sequentially within the eight-month performance period. The study was managed by the Tug Task Team at NASA's Marshall Space Flight Center, along with four other Tug-related contracted avtivities. These other studies, involving ground and flight operations, payload/Tug interfaces, and Tug avionics, supported the interface study by generating accommodation requirements within their respective study areas.

A systematic approach was used to ensure that no interface function was missed or ignored. This approach 1) defined functional requirements derived during Tug/Orbiter operations as they related to determining interface needs, and 2) organized these functional interface requirements to permit systematic evaluation within technical disciplines. Major elements of this approach were: use of operational functional flow diagrams to identify all interface requirements, a safety and reliability assessment of identified operations and interface requirements, and a suitably organized compilation of these interface requirements.

Using these functional requirements, each interface subsystem was evaluated to develop the best implementation technique, and an interface system concept was assembled.

The recommended system concept for supporting and deploying Tug from Orbiter employs a cylindrical load-carrying structure called a deployment adapter. The deployment adapter contains all Tug-peculiar mechanisms required for transfer of Orbiter/ground services and support of deployment, retrieval, and abort operations. Because the deployment adapter is a cylindrical structure to provide efficient axial load distribution, a rotational deployment feature is incorporated to allow Tug removal during deployment without infringing on the Orbiter cargo bay volume available for Tug payloads. By using the deployment adapter concept, Tug umbilical and deployment mechanisms can be attached and checked out before Tug installation into the Orbiter. The entire Tug, adapter, and umbilical support is installed as an autonomous unit into the Orbiter.

Detail description of deployment adapter and other Tug-peculiar peripheral equipment (crew compartment interface panels and cargo bay electrical umbilical kits) were provided as study output. In addition to peripheral equipment definition, use of Orbiter-supplied equipment was investigated.

An evaluation of documented Orbiter payload services (JSC 07700, Vol. XIV, Rev, C) indicated that some changes would be desirable for Tug plus its payloads. Twenty-two proposed changes to this document were prepared by the Space Tug/Shuttle Interface Compatibility Study Team and submitted to MSFC for their assessment and processing. These proposed changes covered detail requirements for Tug service umbilicals, RMS control capability, Orbiter dump/vent provisions, structural attachments, and improved Tug accessability to Orbiter-supplied avionics equipment.

As a final study result, interface areas that would benefit from further technical analyses and predevelopment work have been identified. This suggested additional effort includes structural dynamic response analyses and software design and demonstration in areas of RMS deployment/retrieval control, Tug plus deployment adapter monitor and control, and caution and warning implementation.

TABLE OF CONTENTS

TABLE OF CONTENTS, Contd

TABLE OF CONTENTS, Contd

TABLE OF CONTENTS, Contd

LIST OF FIGURES

LIST OF FIGURES, Contd

LIST OF FIGURES, Contd

LIST OF FIGURES, Contd

LIST OF TABLES

LIST OF TABLES, Contd

SECTION 1

INTRODUCTION

The Space Transportation System flight vehicle, the Space Shuttle, consists of the major segments shown in Figure 1-1. Included as part of this transportation system is a proplusion stage called the Space Tug, depicted in Figure 1-2,which is carried into low-earth orbit by the Space Shuttle in the Orbiter cargo bay. The Tug extends Shuttle capability by placing payloads into higher orbits, such as geosynchronous and interplanetary trajectories, so that more payload users may be accommodated.

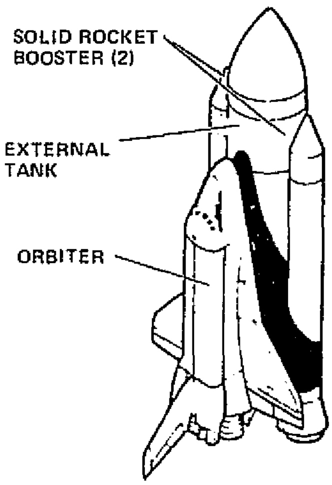


Figure 1-1. Space Shuttle Configuration

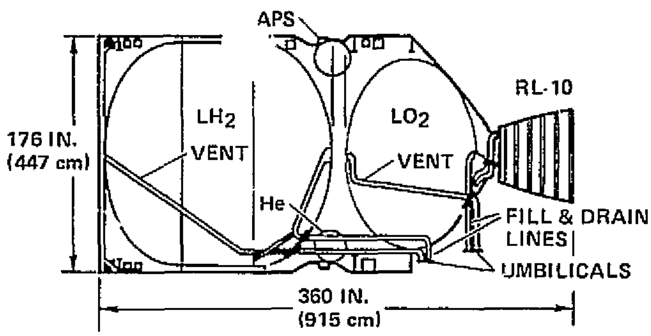


Figure 1-2. MSFC Baseline Tug

1.1 STUDY BACKGROUND AND OBJECTIVES

Current resource constraints preclude simultaneous development of both Space Shuttle and Tug. The government plans to have the Air Force develop an interim upper stage (IUS), to be followed by a NASA-developed full capability Tug at a later date. The IUS is planned to be operational at or near the Shuttle's initial operational capability (IOC). Although the Space Tug operational date is planned for 1983, it is important that Shuttle/Tug interface requirements will be identified early so that they can be incorporated into the Shuttle. This will prevent having to constrain the Tug design due to prior Shuttle development. This advanced planning will also avoid major and costly Shuttle modification when Tug is introduced.

The Space Tug/Shuttle Interface Compatibility Study was structured to compile, screen, evaluate, and recommend suitable Orbiter interface provisions for Space Tug integration.

The Shuttle/Orbiter, as currently configured, includes some general payload accommodations applicable for Space Tug, but a detailed investigation of specific interface requirements had not previously been undertaken. Tug interface requirements needed immediate definition and consideration in conjunction with other payload interface

requirements for incorporation into the Shuttle Orbiter at the earliest possible date. Tug/Shuttle interface compatibility achieved early during Shuttle development will result in lower Space Transportation System program costs.

The purpose of the Space Tug/Shuttle Interface Compatibility Study was to provide 1) timely detailed identification of Tug-related interface requirements, and 2) the instrument by which design changes to satisfy these requirements were submitted to NASA. Figure 1-3 identifies the Tug-related Orbiter interfaces for the MSFC baseline cryogenic Tug.

The Interface Study was managed by the Tug Task Team at NASA's Marshall Space Flight Center, along with four other parallel Tug-related contracted activities. These other studies, involving ground and flight operations, payload/Tug interfaces, and Tug avionics, supported the Interface Study by generating accommodation requirements within their respective study areas.

1.2 FINAL REPORT ORGANIZATION

The results of the Space Tug/Shuttle Interface Compatibility Study are contained in the four volumes of the final report. The four volumes are organized as follows:

Volume I — Executive Summary — Contains in summary form the objectives, relationship of the Interface Study to other NASA efforts, approach, data generated and significant results, limitations, research implications, and recommendations for additional effort made as a result of the study.

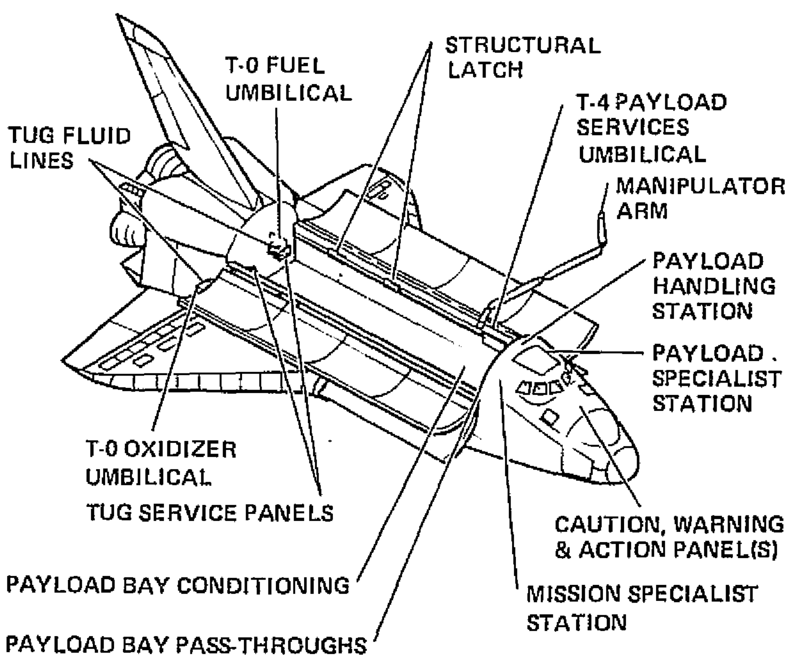


Figure 1-3. Tug-Related Orbiter Interface Provisions

Volume II Tug/Payload/Orbiter Interface Analysis — Includes the subsystem technical analysis performed, including the definition of the Tug functional interface requirements and payload service requirements, detailed analyses and trade studies of Tug/Orbiter interfaces, appropriate sensitivity studies, and special emphasis tasks.

Volume III Tug/Payload/Orbiter Interface Requirement — Contains the system level interface assessment and the operation/physical definition of the recommended Tug/Orbiter interface, plus a description of the Orbiter and baseline Tug changes needed to accommodate the recommended interface. It also includes a comparison of IUS and Tug interface requirements, and recommends interface simulation-demonstration candidates.

Volume IV Cost Analysis — Provides the detailed study economic analysis approach, methodology, and results.

The study was arranged into six tasks, which were accomplished sequentially within the eight-month performance period:

Task 1 - Functional Interface Requirements Definition. Tug ground and flight operations were analyzed to obtain a complete accounting of all potential Tug/Orbiter interfaces, their related operations, and safety functional requirements. This analysis was conducted using baseline vehicle and operations definitions supplied by NASA-MSFC at the start of the study effort.

Task 2 - Baseline Tug Interface Analyses. Approved functional interface requirements were systematically evaluated to obtain alternative solutions and determine the optimum interface approach to satisfy each baseline Tug need. Specific payload through Tug and direct to Orbiter service requirements obtained by trade study were included. From these subsystem investigations and trade studies, detailed interface requirements for Tug/Shuttle compatibility were itemized.

Task 3 - Sensitivity Analysis. Using updated subsystem requirements from Task 2, sensitivity analyses were performed to evaluate the effect of Tug operations and design changes on Tug/Orbiter interface requirements.

Task 4 - Tug/Orbiter Interface Requirements. Results from baseline Tug interface analyses (Task 2) were assembled through a total Tug systems interface concept trade study, and a composite set of preliminary Tug/payload/Orbiter interface requirements were submitted for NASA evaluation. These proposed Orbiter accommodation revisions were submitted as recommended Level II changes. The NASA assessment included requirements reviews by MSFC and the Shuttle project.

Task 5 - Interface and Baseline Revisions. Revised interface requirements were prepared in areas where the government disapproved the initial requirements. Revisions

were defined through trade studies of alternative approaches and baseline Tug changes. Since relatively few proposed changes were rejected, unused resources were applied to Tug/Orbiter interface related special emphasis tasks.

Task 6 - IUS/Tug Interface Comparison. Approved Tug requirements from Tasks 4 and 5 were compared with similar IUS requirements. Interface requirement incompatibilities were evaluated to identify and define major problems and recommend compromise solutions.

1.3 VOLUME III ORGANIZATION

The Tug/payload/Orbiter interface requirements, contained in this volume of the final report, consist of work performed under Study Tasks 4, 5, and 6. The overall requirements objective was to obtain the best interfaces (simple, flexible, and functional) for Tug within the constraints imposed by the Orbiter. The Interface Study under Tasks 4 and 5, evaluated a large variety of Tug/payload accommodation techniques, compared recommended implementation methods with current Orbiter provided payload services, defined peripheral and proposed equipment requirements and recommended 22 Orbiter accommodations changes to improve interface services.

Sections 2 through 6 in this requirements volume are arranged to present the various aspects of the development, operational use, and vehicle implementation of Tug/Orbiter interfaces:

2. System trade study used to obtain the recommended interface approach.
3. Operational interface description.
4. Definition of special peripheral equipment for Tug/Orbiter interface.
5. Definition of desired Orbiter accommodations interface revisions.
6. Definition of associated Tug design changes.

Section 7, IUS/Tug Interface Comparison, reports activity accomplished under Study Task 6. It contains a comparison of interface requirments for the five expendable interim upper stage (IUS) candidates with the interface requirements developed in preceding tasks for Space Tug.

Section 8 contains implications for additional research in areas related to Tug/Orbiter interfaces. It defines technical analyses, predevelopment activity, and supporting research and technology work still needed in the interface area.

SECTION 2

SYSTEM LEVEL ASSESSMENT

This section describes the approach employed, trade studies performed, and recommendations made for assessment of alternative Tug/Orbiter support and deployment system concepts. Three system concepts, shown in Figure 2-1, were postulated for use during the Tug subsystem interface analyses and trade studies work performed under Study Task 2. Section 4.1, Volume 2 delineated these three support/deployment concepts used at task initiation to ensure that viable subsystem options associated with each of these concepts were considered.

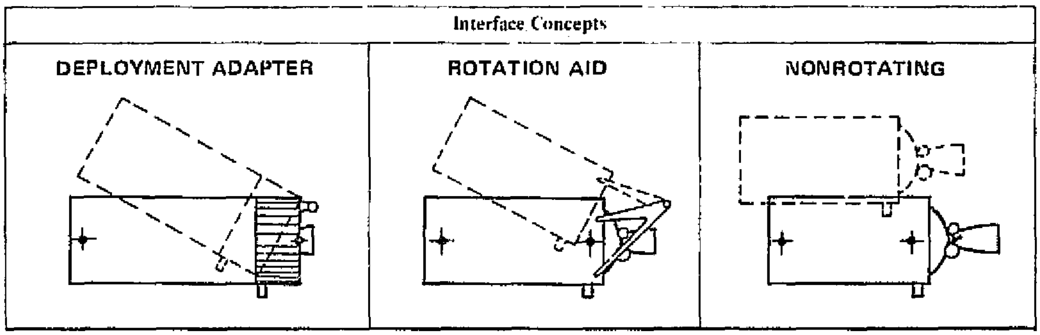


Figure 2-1. Support/Deployment System Concepts

The following paragraphs describe the major differences between these concepts.

The deployment adapter concept includes a support/deployment adapter. It distributes Orbiter attach fitting point loads into the Tug shell and provides positive positioning during initial deployment, alignment for docking, and a convenient mounting place for Tug peripheral equipment (avionics, abort helium supply).

The nonrotating concept eliminates the support adapter and its attendant load distribution and relatively complex deployment, retrieval, rotation, and latching functions. Orbiter attachment fitting point loads are taken directly into the Tug shell, requiring frame beefup and resulting in a general Tug weight increase. Rotation is eliminated; deployment/recovery is accomplished linearly with the manipulator, as similarly proposed for the Large Space Telescope. Support equipment previously located in the baseline adapter is mounted to the payload bay in racks.

The rotation aid concept is a compromise configuration. Orbiter fitting loads are taken directly by the Tug structure as in nonrotating, but a non-flight-loadcarrying

rotation yoke may be incorporated if required to aid in deployment, docking and retrieval.

A fourth concept, using nonrotating deployment in conjunction with an Orbiter longeron-mounted positioning device, was also investigated. This approach, using two arms with docking drogues rotating about an axis parallel to the cargo bay door hinge, was proposed by JSC late in the interface study.

The work described here integrates composite system concepts from previously developed subsystem definitions (Section 4, Volume II) and appropriate sensitivity analyses considerations (Section 5, Volume II). Once these support/deployment systems were properly defined, a comparative assessment was performed to select the best Tug/Orbiter interface concept.

Section 2.1 presents configuration details and operational considerations of each system concept; Section 2.2 gives the comparative assessment; Section 2.3 evaluates system level effects associated with the use of a forward umbilical. The forward umbilical investigation has been segregated from the systems candidates since its implementation is independent of system concept selection. Section 2.4 presents the recommended support/deployment system.

2.1 SUPPORT/DEPLOYMENT CONCEPT DEFINITION

Definition of four Tug/Orbiter interface concepts is included. This definition consists of each candidate's configuration description and operational considerations. The four concepts are the deployment adapter, rotation aid, nonrotating, and JSC lateral rollout techniques described briefly in the introduction. Details of these concepts necessary for subsequent comparative analysis are presented in the following text.

The candidate concepts are physically described by drawings, deployment sequences are outlined, and preliminary accessibility concepts are presented in supporting documentation. Subsequent to the outcome of this comparison study, additional changes to the selected Tug/Orbiter interface concept were made. These changes further enhanced the attributes of the selected version and in no way invalidated the results of the system level comparison. The configurations defined and comparisons made were accomplished before incorporation of these final design improvements.

2.1.1 DEPLOYMENT ADAPTER. The deployment adapter (D/A) system concept shown in Figure 2-2 is very similar to the MSFC baseline Tug concept. The deployment adapter is a cylindrical composite structure 176 inches (4.47 m) in diameter and 75 inches (1.91 m) long. The Tug is connected to the deployment adapter by 16 mechanical latches. The Tug-D/A is supported from the Orbiter by either a four-point determinate or five-point redundant system with X-Z fittings coincident with the pivot at station 1246, Z only fitting(s) at station 951 and the Y fitting at station 1249. An

Table 2-1. Deployment Adapter Deployment/Retrieval Operational Sequence

Deployment Events	Mechanism
Retract Umbilical Panels	Panel actuators
Unlatch forward Tug fittings	*
Rotate Tug/adapter out of bay	Pivot actuators
Attach RMS to Tug	*
Unlatch Tug from adapter	Adapter latches
Push apart Tug from adapter	Adapter latches
Move Tug axially out of adapter with RMS	*
Extend Tug away from Orbiter with RMS	*
Rotate Tug perpendicular to Orbiter with RMS	*
Release RMS from Tug	*
Thrust Orbiter away from Tug	*
Rotate adapter back into bay if required by Orbiter mission	Pivot actuators
Retrieval Events	
Rotate adapter out of bay	Pivot actuators
Actuate latches to unlocked	Adapter latches
Position Orbiter perpendicular to Tug	*
Extend RMS - align to Tug fitting using manual control & TV monitor	*
Attach RMS to Tug	*
Align Tug to adapter - computer controlled	*
Move Tug axially into adapter - computer control with manual override & TV monitor	*
Tug enters alignment guides	Adapter guides
Clamp & lock tug to adapter	Adapter latches
Release RMS from Tug	*
Rotate Tug/adapter into bay	Pivot actuators
Latch forward Tug fittings	*
Engage umbilical panels	Panel actuators

*Orbiter supplied equipment operation

technician access to the fuel and oxidizer interface panels on the Orbiter aft bulkhead (station 1307) is required to connect or disconnect fluid lines and electrical lines. For horizontal installation and removal at the Orbiter processing facility (OPF), this access can be provided using a concept shown in Figure 2-4. A simple ladder can be attached to a holding fitting on the edge of the OPF Orbiter work platforms and pick up a support point on the top of the wing box at the keel line. A folding or modular work platform is then installed in the location shown, which provides ready access to both the fuel and oxidizer panel locations on the aft bulkhead. The platform location suggested here has adequate clearance for rapid ingress/egress, and the MLI and the payload bay liner atop the wing box will be protected from scuffing or abrasion.

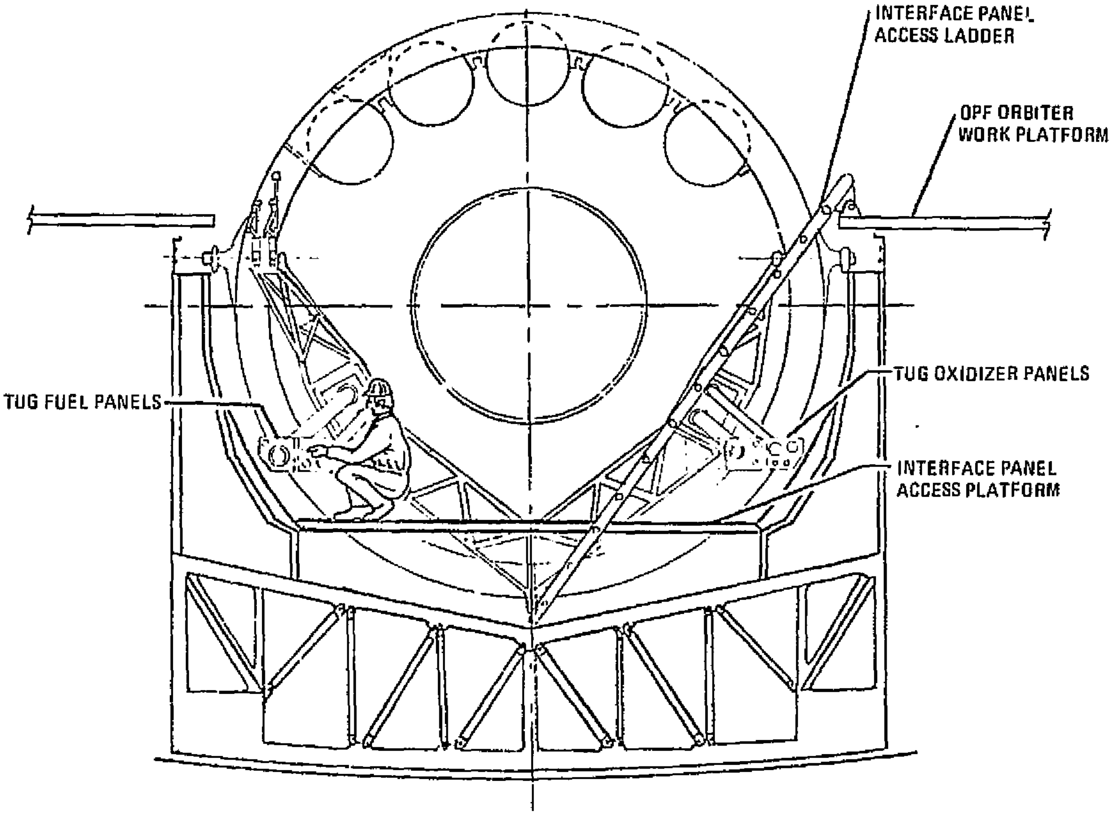


Figure 2-4. Deployment Adapter Horizontal Access

For vertical installation or payload changeout at the launch pad, a work platform similar to that shown in Figure 2-5 will provide technician access to the Tug interface panels on the aft bulkhead. It is assumed that a basic payload changeout room (PCR) work platform will provide access to the aft bulkhead area. Two small, sliding extensions mounted as shown will extend access capability along the sides of the Tug main engine exhaust nozzle to the vicinity of the interface panels. If required, support struts can be attached to the end of the platform and hung from the subsystem support

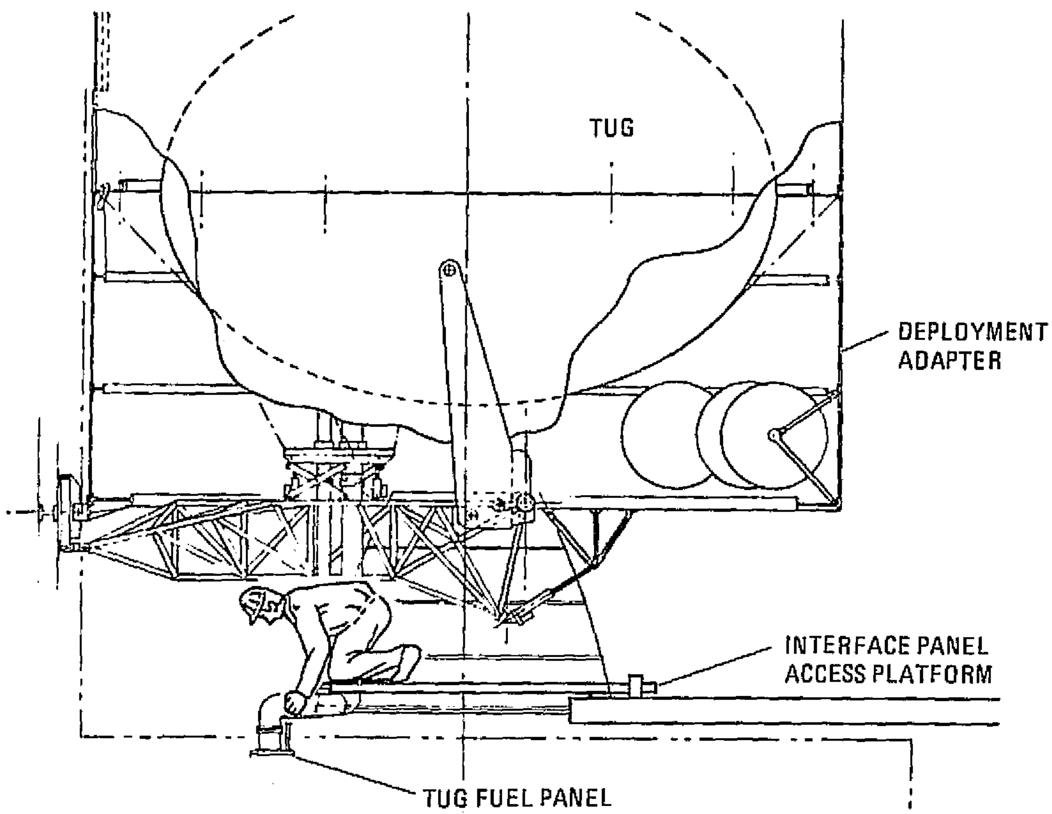


Figure 2-5. Deployment Adapter Vertical Access

structure to provide additional stability. The platform, in addition to providing basic panel access, also protects the insulation installed on the 1307 bulkhead.

2.1.2 DIRECT SUPPORT WITH LATERAL DEPLOYMENT (NONROTATING). An alternative structural support concept, shown in Figure 2-6, deletes the deployment adapter and attaches all the Tug support fittings directly to the Tug structural shell. Either four-point determinate, or five-point singly redundant are viable options for this direct support concept. X-Z fittings are located at station 1187, and Z only fitting(s) at station 951, and the Y fitting at station 1181. An alternative Y fitting location near the Tug CG (station 1128) is also being considered. All Orbiter attachment fittings and bridge beams are standard including the Y fitting, since lateral rather than rotational deployment is used.

Tug and spacecraft umbilicals are routed through three retractable umbilicals. The option for a fourth hardwired safety umbilical is not practical, since hard Tug-to-Orbiter and Tug-to-peripheral equipment alignment is immediately terminated upon structural release. The aft fluid umbilicals and the abort helium pressurization bottles are mounted on a subsystem support structure. The Tug electrical and spacecraft service forward umbilical panel is mounted in a modified Orbiter keel bridge fitting. All three panels are oriented so that their separation plane and retraction motion are normal to the lateral deployment movement. The subsystem support

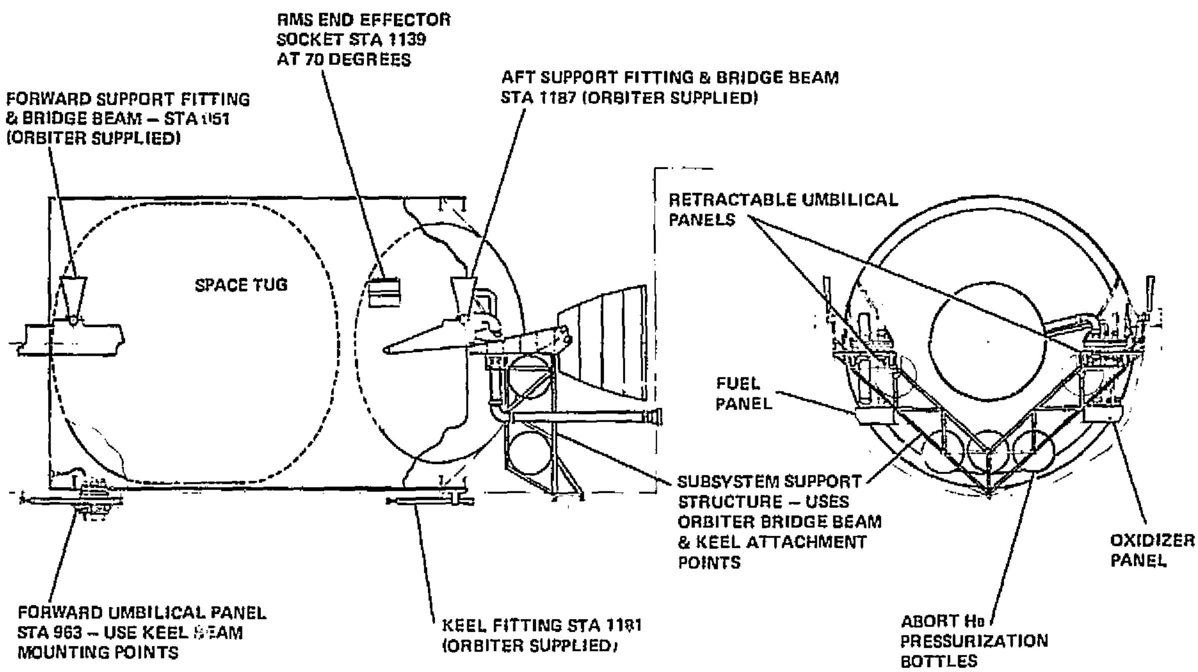


Figure 2-6. Direct Support with Lateral Deployment System Concept

structure, which holds the umbilical panels, fluid lines, and helium bottles, is attached to the Orbiter by using the Orbiter-provided bridge beam attachment points. No new structural interface requirements result from this technique.

Ground installation would be accomplished by installing the subsystem support structure (including the fluid service lines) concurrent with the Tug support bridge beams. Later Tug installation would involve support fitting attachment followed by engagement/mating of the three umbilical panels, functional engagement/disengagement testing and leak tests. Support adapter elimination results in increased Tug shell weight due to the addition of load distribution material but also deletes the requirement for two mechanisms needed with the D/A concept: rotation actuators, and Tug to D/A structural latches.

The lateral deployment technique possible for a directly supported Tug is basically more straightforward than D/A rotation since fewer mechanisms are involved. The elimination of these mechanisms, however, results in considerably greater RMS dependence. Figure 2-7 depicts the deployment sequence. Events are identified in Table 2-2.

Following accomplishment of the Tug-Orbiter predeployment procedures, the RMS is released from its stowed position and attached to the Tug RMS end effector socket, umbilicals are retracted, and the support fittings released. The Tug is laterally translated out of the payload bay in the Z direction with the RMS until clear of the

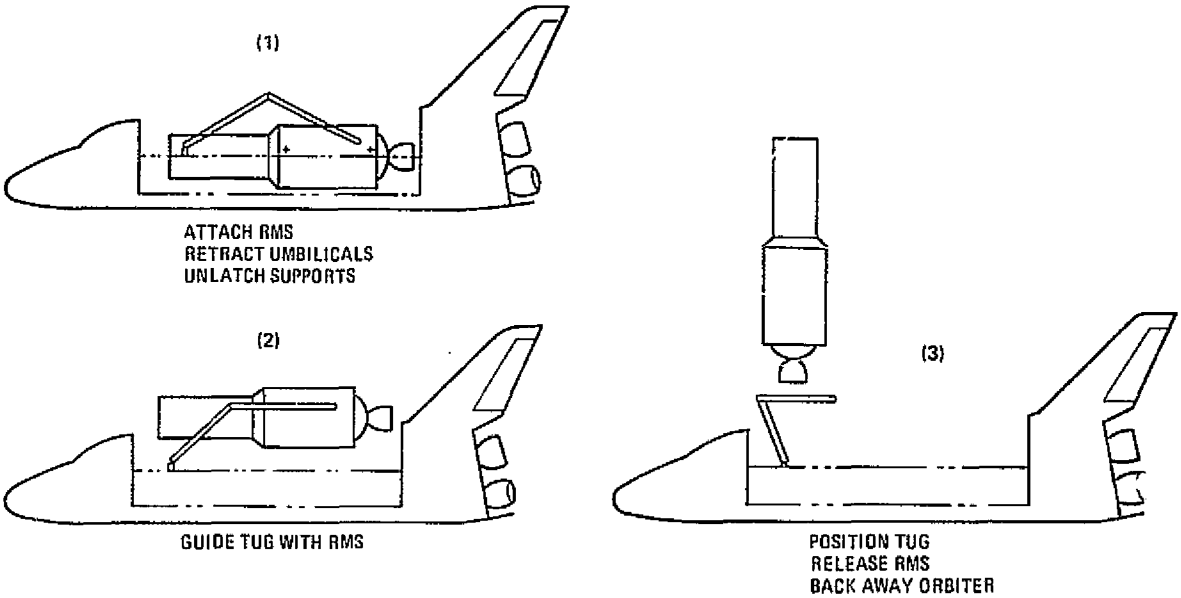


Figure 2-7. Deployment with Direct Support

Orbiter mold line. At this point rotation is initiated to reach the Tug perpendicular, engine-down attitude at maximum RMS reach. Tug release, Orbiter backaway, and Tug ACS activation are then accomplished.

Tug retrieval is the reverse of the above procedure. Particular interest in the RMS capability (including operator capability) to place the Tug back into the payload bay fittings has been generated. Direct visual alignment by the RMS operator does not appear to be practical. The use of special alignment aids will probably be required.

Ground operations access to the 1307 bulkhead interface panels during horizontal installation and removal for a Tug using either of the direct support concepts is accomplished in the same manner as shown for the deployment adapter configuration. Figures 2-8 and 2-9 show the interface panel access ladder secured to a holding fitting on the edge of the OPF Orbiter work platforms and resting on a fitting at the base of the subsystem support structure and a hardpoint on top of the wing box at the keel line. In these two figures the Tug has been omitted to indicate how the subsystem support structure can be installed in the cargo bay. Access to the special bridge fitting attach locations can be attained using the Orbiter payload bay movable work platform. The fluid interface panels are reached using the panel access ladder and platform as in the baseline configuration. These also provide access once the Tug has been installed. Clearance remains adequate, as indicated by the dashed-line reference location for the main engine nozzle exit. Access to install the special bridge fittings and payload forward umbilical panel at the keel line is attained using the Orbiter payload bay movable work platform for this and the rotating deployment adapter concepts. As with the deployment adapter support concept, this very similar work platform concept will ensure

Table 2-2. Direct Support Nonrotating Deployment/Retrieval Operation Sequence

Deployment Events	Mechanism
Attach RMS to Tug	*
Retract umbilical panels	Panel actuators
Unlatch Tug/longeron support fittings	*
Move Tug radially out of Orbiter with RMS	*
Extend Tug away from Orbiter with RMS	*
Rotate Tug perpendicular to Orbiter with RMS	*
Release RMS from Tug	*
Thrust Orbiter away from Tug	*
Retrieval Events	
Position Orbiter perpendicular to Tug	*
Extend RMS - align to Tug fitting using manual control & TV monitor	*
Attach RMS to Tug	*
Move Tug into Orbiter bay - computer control with manual override & TV monitor	*
Rotate lock Tug to Orbiter	*
Engage umbilical panels	Panel actuators
Remove RMS from Tug	*

*Orbiter supplied equipment operation

protection of the MLI and payload bay liner atop the wing box from scuffing and abrasion.

Access to the 1307 bulkhead interface panels during vertical installation or payload changeout can be attained using a work platform similar to that shown in Figure 2-5 for the rotating deployment adapter concept. Again, it is assumed that a basic payload changeout room work platform provides access to the aft bulkhead area. Sliding extensions extend access capability along the sides to the Tug main engine exhaust nozzle to the vicinity of the interface panels. If required, support struts can be attached to

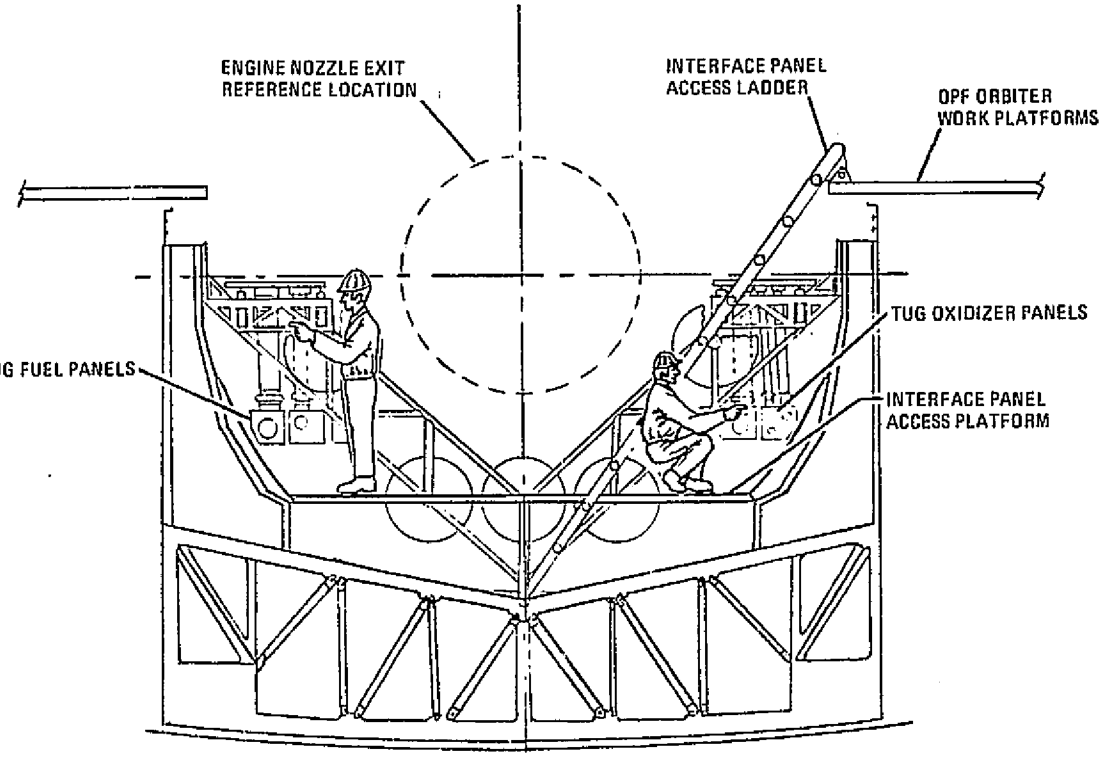


Figure 2-8. Direct Support Concept Horizontal Access (End View)

the end of the platform and hung from the subsystem support structure to provide additional stability. The platform and work stand provide access to the bulkhead interface panels and the subsystem support structure to Tug interface area and protect the 1307 bulkhead insulation as well.

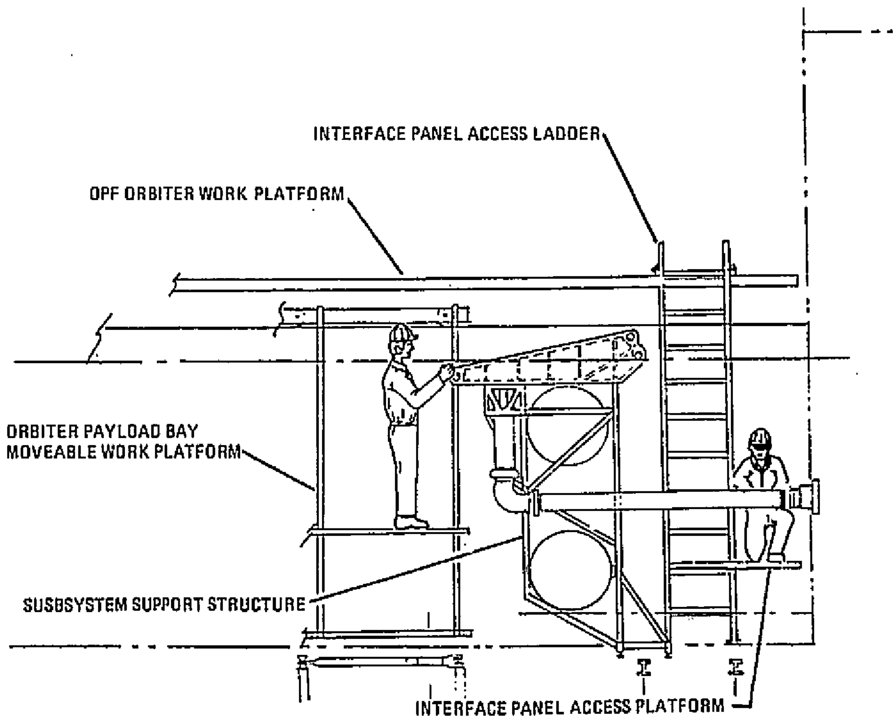


Figure 2-9. Direct Support Concept Horizontal Access (Side View)

2.1.3 DIRECT SUPPORT WITH ROTATIONAL DEPLOYMENT (ROTATION AID). This adapterless concept, shown in Figure 2-10, is a hybrid of the two support techniques described previously. The Tug is directly Orbiter supported through its structural shell, but uses initial rotation to provide controlled clearance with the Orbiter during deployment. The structural support locations are identical to the direct support with lateral deployment concept to provide rotation clearance.

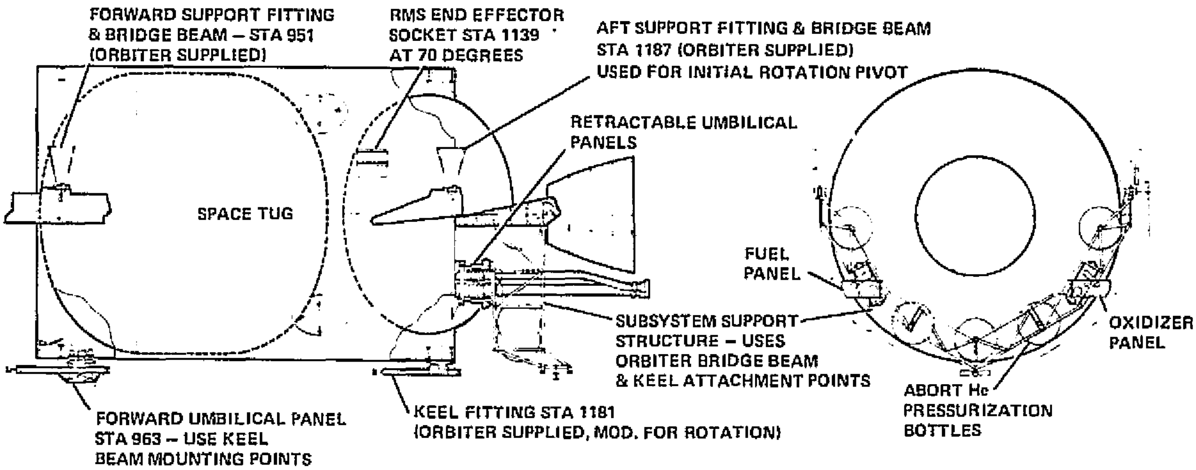


Figure 2-10. Direct Support with Rotational Deployment

The umbilical panel arrangement is similar to the deployment adapter concept. A subsystem support structure is used for mounting the two fluid umbilicals and the abort helium pressurization bottles. The retractable fluid panels are oriented so that rotation about the station 1187 X/Z support fitting will allow panel disengagement in the event of retraction actuator failure. The forward retractable umbilical panel contains Tug electrical, power, and spacecraft services and is mounted in a modified Orbiter keel bridge beam. A fourth safety hardwired electrical umbilical is not practical with this rotational deployment concept, since no peripheral structure rotates along with the Tug from which to mount the umbilical.

Attachment of the subsystem support structure in the Orbiter payload bay is through the standard Orbiter supplied attachments provided for bridge beams. The umbilical panel/He bottle/fluid lines support structure is installed, before Tug installation, in the Orbiter concurrent with the Tug support beams and fittings.

The deployment procedure for the direct support with rotational deployment concept, shown in Figure 2-11 and operationally described in Table 2-3, is a combination of the operations described previously for D/A rotation and direct support lateral deployment. Following accomplishment of the Tug-Orbiter predeployment procedures, the RMS is released from its stowed position and attached to the Tug RMS end effector

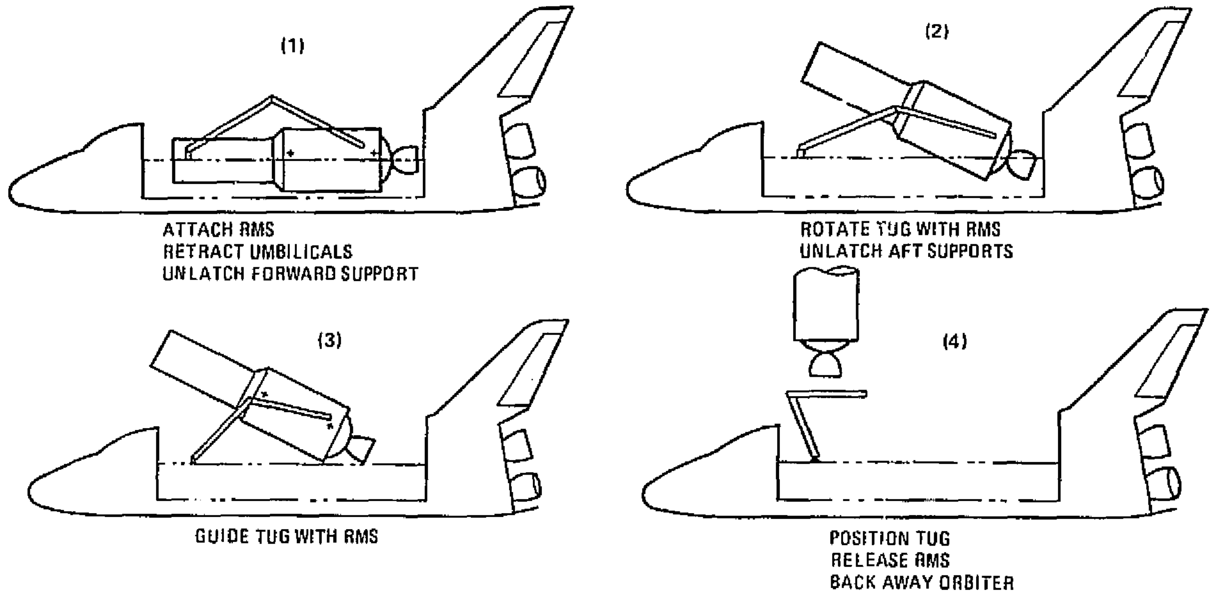


Figure 2-11. Deployment with Direct Support and Pivot for Clearance

socket, umbilicals are retracted, and the forward Z support fitting(s) are released. The Tug is rotated approximately 25 degrees with the RMS about station 1187, using the X/Z fittings as trunnions. When rotation is complete, the X/Z support fittings are released, and the RMS translates the Tug up and forward out of the cargo bay to obtain maximum clearance with the Orbiter. Final positioning and release are performed as indicated previously.

Tug retrieval is accomplished in reverse. Location of the X/Z fittings during placement of the Tug back into the payload bay is of special interest in evaluating RMS requirements and its operational acceptability.

Ground access considerations in both horizontal and vertical positions for this support/deployment system concept are similar to those described for the two previous concepts.

2.1.4 DIRECT SUPPORT WITH ROLL-OUT DEPLOYMENT. During the latter phases of interface study activity, a standard (Orbiter provided, payload chargeable) positioning/docking aid for payload use was proposed by Johnson Space Center (JSC). This concept, shown in Figure 2-12, provides position control with standard Orbiter equipment, rather than with special Tug peripheral equipment as proposed in the deployment adapter concept (reference Section 2.1.1). Both the JSC roll-out and deployment adapter concepts provide rotational deployment constraints for removing/inserting Tug in the cargo bay, but about different axes. Whereas the D/A pivots about the aft X/Z primary support points, the rollout device pivots about the cargo bay longeron (parallel to the cargo bay door hinge).

Table 2-3. Direct Support Rotating Deployment/Retrieval Operational Sequence

Deployment Events	Mechanism
Attach RMS to Tug	*
Retract umbilical panels	Panel actuators
Unlatch forward Tug fittings	*
Rotate Tug with RMS	*
Unlatch aft Tug fittings	*
Move Tug out of Orbiter with RMS	*
Extend Tug away from Orbiter with RMS	*
Rotate Tug perpendicular to Orbiter with RMS	*
Release RMS from Tug	*
Thrust Orbiter away from Tug	*
Retrieval Events	
Position Orbiter perpendicular to Tug	*
Extend RMS - align to Tug fitting using manual control & TV monitor	*
Attach RMS to Tug	*
Move Tug into aft fittings using RMS - computer control with manual override & TV monitor	*
Latch aft Tug fittings	*
Rotate Tug into Orbiter with RMS	*
Latch forward Tug fittings	*
Engage umbilical panels	Panel actuators
Remove RMS from Tug	*

*Orbiter supplied equipment operation

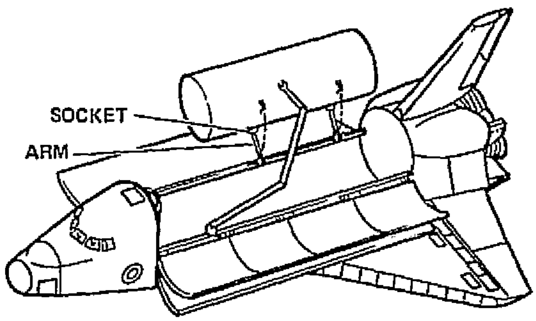


Figure 2-12. JSC Rollout Concept

The rollout mechanism consists of two arms with end mounted docking sockets. These arms are activated together to roll the payload into or out of the cargo bay. The Tug/peripheral equipment configuration that is compatible with the rollout deployment concept is shown in Figure 2-13. It is similar to the non-rotating concept described in Section 2.1.2, since there is no deployment adapter, and all the Tug support fittings attach directly to the Tug structural shell. Either four-point determinate, or five-point singly redundant are viable options for this direct support concept. X-Z fittings are located at station 1187, and Z only fitting(s) at station 951, and the Y fitting at station 1181. An alternative Y fitting location near the Tug CG (station 1128) was also considered. All Orbiter attachment fittings and bridge beams are standard except the Y fitting, which must be modified to accommodate the side motion caused by pivoting about the longeron-mounted arm pivots.

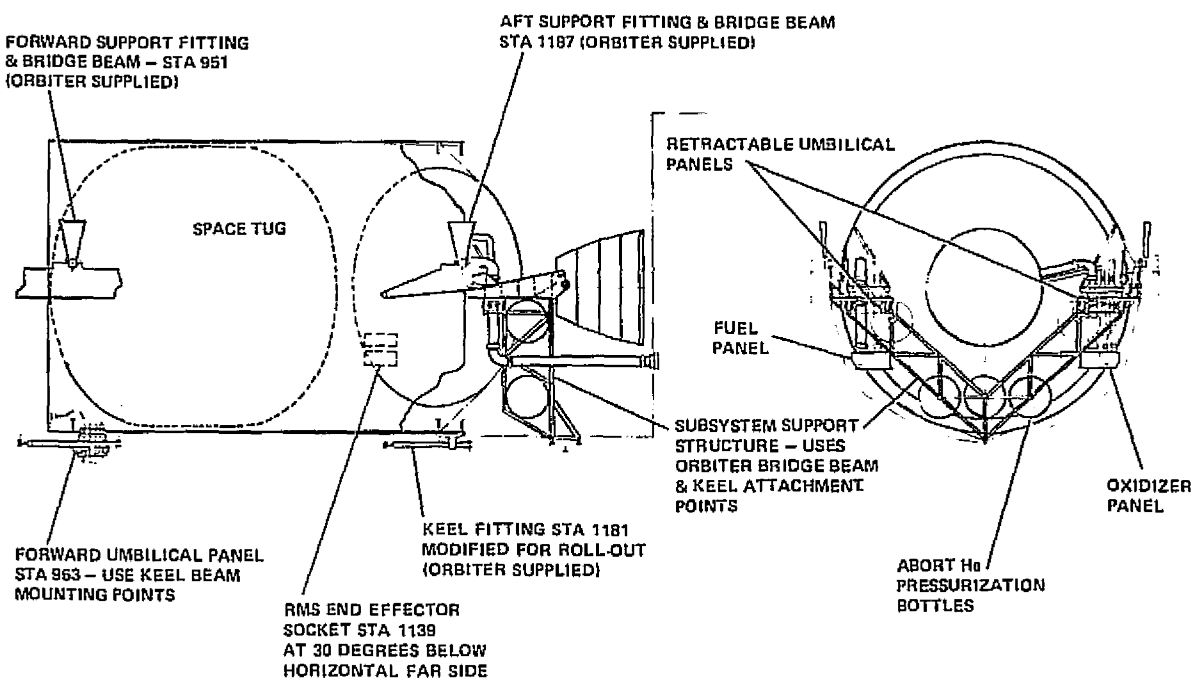


Figure 2-13. Direct Support with Rollout Deployment System Concept

Tug and spacecraft umbilicals are routed through three retractable umbilicals. The option for a fourth hardwired safety umbilical is not practical, since hard Tug-to-Orbiter and Tug-to-peripheral equipment alignment is immediately terminated upon structural release. The aft fluid umbilicals and the abort helium pressurization bottles are mounted on a subsystem support structure. The Tug electrical and spacecraft service forward umbilical panel is mounted in a modified Orbiter keel bridge fitting. All three panels are oriented so that their separation plane and retraction motion are normal to initial rollout deployment movement.

The RMS end effector socket is located at 30 degrees ($\pi/6$ rad) below horizontal centerline on the opposite Tug side, as indicated in Figure 2-13. This location provides proper socket positioning for RMS attachment after the rollout arms have removed Tug from the bay and rotated it (about its centerline) through 150 degrees ($5/6\,\pi$ rad).

The subsystem support structure that holds the umbilical panels, fluid lines, and helium bottles is attached to the Orbiter by using the Orbiter-provided bridge beam attachment points. No new structural interface requirement results from this technique.

Ground installation would be accomplished by installing the subsystem support structure (including the fluid service lines) concurrent with the Tug support bridge beams. Later Tug installation would involve support fitting attachment followed by engagement/mating of the three umbilical panels, functional engagement/disengagement testing, and leak tests.

Support adapter elimination results in increased Tug shell weight due to the addition of load distribution material. The Tug-peculiar mechanisms that were deployment-adapter mounted (rotation actuators and latches) are replaced with Orbiter mechanisms of equal complexity (rollout positioning arms).

Deployment/retrieval events and their associated mechanisms are identified in Table 2-4. The event sequence is similar to deployment/retrieval with a deployment adapter with two exceptions:

a. The mechanisms (with the exception of the umbilical panel actuators) are all Orbiter supplied.

b. No opportunity exists for maintaining hardware umbilical connections through early stages of deployment.

Figure 2-14 depicts the rollout movement used for Tug installation.

Ground access considerations in both horizontal and vertical attitudes are identical to those presented in Section 2.1.2.

Table 2-4. Direct Support Rollout Deployment/Retrieval Operational Sequence

Deployment Events	Mechanism
Retract umbilical panels	Panel actuators
Unlatch Tug/longeron support fittings	*
Roll out Tug with arms	*
Attach RMS to Tug	*
Release rollout arms	*
Move Tug away from arms with RMS	*
Rotate Tug perpendicular to Orbiter with RMS	*
Release RMS from Tug	*
Thrust Orbiter away from Tug	*
Retrieval Events	
Position Orbiter perpendicular to Tug	*
Extend RMS - align to Tug fitting using manual control & TV monitor	*
Attach RMS to Tug	*
Position Tug over arm sockets with RMS	*
Dock Tug to arm	*
Release/remove RMS from Tug	*
Roll in Tug with arms	*
Latch Tug/longeron support fittings	*
Engage umbilical panels	Panel actuators

*Orbiter supplied equipment operation

2.2 SUPPORT/DEPLOYMENT CONCEPT EVALUATION

The four system interface concepts described in the preceding section were subjected to a comparative investigation to determine the best concept. These deployment/support system interface concepts include both deployment adapter and directly

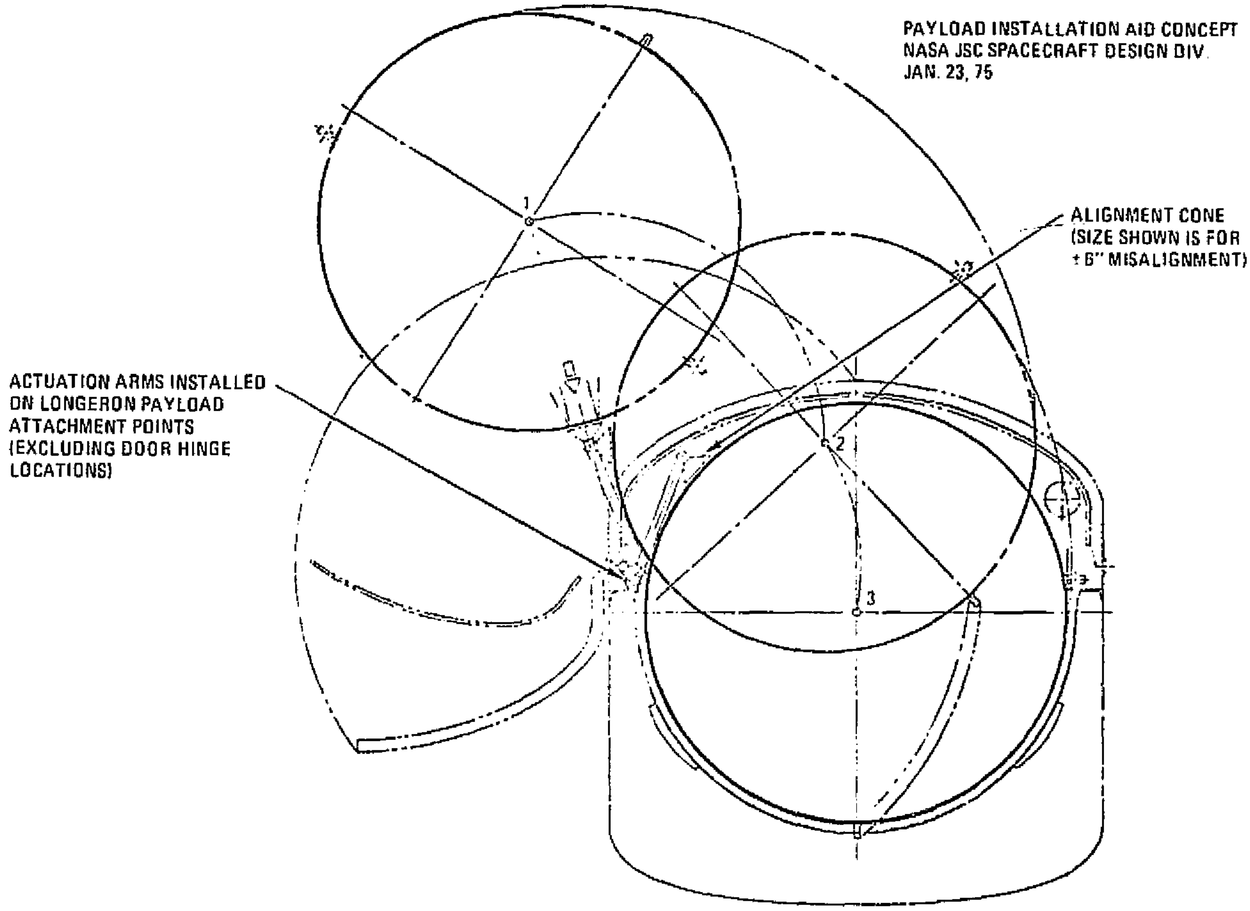


Figure 2-14. Tug Movement for Rollout Deployment Concept

supported techniques and were comparatively evaluated for operational, safety/ reliability, weight/performance, and cost impacts.

The following text describes the factors considered and analyses conducted. Final system selection and recommendations are contained in Section 2.4.

2.2.1 OPERATIONAL COMPARISON. The two considerations of primary importance for operational interface comparison are communications transfer (hardware to RF), and position control for Tug payload bay removal and insertion.

The Orbiter RF transmission/receiving capability precludes RF link establishment with Tug when the Tug is in the payload bay. This is caused by the top crew compartment mounting location of the Orbiter antenna. The only deployment/support concept that can readily effect a hardware-to-RF communications handoff without a deadband is the deployment adapter. With the D/A rotational deployment technique, hardwires can be maintained across the D/A-to-Tug interface through rotation. At a rotation angle of approximately 35 degrees, Tug RF equipment mounted on the forward portion

of the structural shell is within the Orbiter transmission/receiving envelope. RF communications can be established and verified before breaking the D/A-to-Tug hard-wired connections. None of the other three deployment concepts offer a similar hard-wired communications capability through sufficient deployment motion to eliminate a handoff deadband. Communications deadbands are an extremely important issue for the safety comparison conducted in Section 2.2.2 following.

The second major comparison consideration of deployment concepts is Tug ability to deploy and return to the cargo bay without damage to either Tug or Orbiter. A clearance study of the four concepts, shown in Figure 2-15, indicates the use of a position control device is desirable.

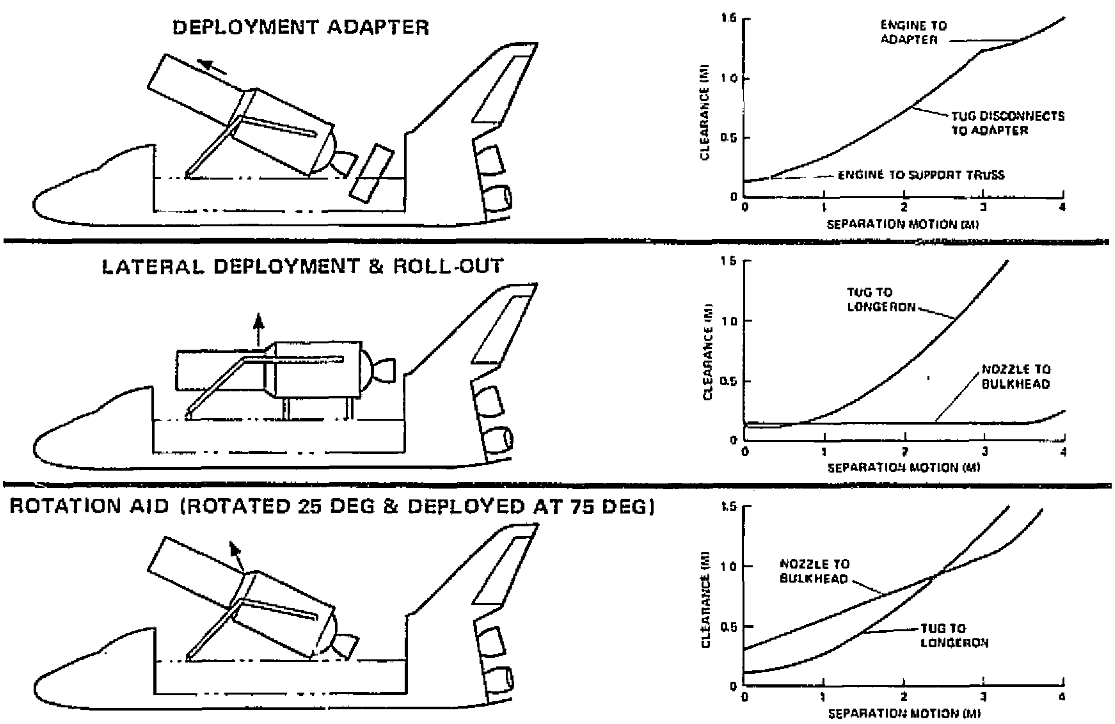
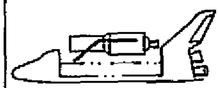
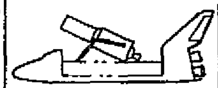
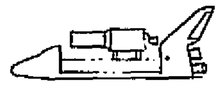


Figure 2-15. Tug Support System Concepts - Deployment Clearance Comparison

The center analysis shown in Figure 2-15 applies to both the lateral and rollout deployment concepts. For directly supported lateral and rollout deployment, the engine nozzle to Orbiter bulkhead clearance is approximately 6 in. (15 cm) for a deployment travel of about 11.5 ft (3.5 m) and allows little room for error. For both the direct supported Tug with rotated deployment and the Tug with an adapter, the clearance is initially about 6 in. (15 cm) but increases rapidly to an acceptable value.

Orbiter safety favors the use of the deployment adapter or rollout arm concept in that accidental contact will occur between the Tug and adapter or arm, thus preventing damage to the Orbiter. Damage to the Tug is minimized by alignment guides or sockets; however, the entire cargo can be jettisoned if required for safe Orbiter return.

Figure 2-16 contains the operational comparison of the four interface concepts. The following comments and observations are included for each alternative concept.

EVENT DESCRIPTION	ADAPTER 	LATERAL WITH RMS 	ROTATE WITH RMS 	ROLL-OUT WITH ARMS 
<u>INSTALLATION/REMOVAL</u>				
PRE TUG EQUIPMENT INSTALLATION IN ORBITER	CABIN AVIONICS, SERVICE LINE & PANELS, & SUPPORT FITTINGS	SAME PLUS TUG SUBSYSTEM SUPPORT STRUCTURE	SAME PLUS TUG SUBSYSTEM SUPPORT STRUCTURE	SAME PLUS TUG SUBSYSTEM SUPPORT STRUCTURE & ARMS
PERIPHERAL EQUIPMENT INSTALLED WITH TUG	DEPLOYMENT ADAPTER	NONE	NONE	NONE
<u>DEPLOYMENT/RETRIEVAL</u>				
RETRACT UMBILICALS	FLUID (ACTUATORS)	ALL (ACTUATORS) (COMM DEADBAND)	ALL (ACTUATORS) (COMM DEADBAND)	ALL (ACTUATORS) (COMM DEADBAND)
STRUCTURAL RELEASE	FORWARD (OSE)	ALL (OSE)	FORWARD (OSE)	ALL (OSE)
ROTATION	D/A (ACTUATORS)	N/A	RMS (OSE)	ARMS (OSE)
RMS ATTACHMENT	RMS (OSE)	N/A	PREVIOUS STEP	RMS (OSE)
STRUCTURAL RELEASE	D/A (LATCHES)	N/A	AFT (OSE)	ARMS (OSE)
DISENGAGE UMBILICALS	ELECT. (LATCHES)	N/A	N/A	N/A
REMOVAL FROM D/A, ARMS OR CARGO BAY	ESTABLISH RF ROTATED RMS (OSE)	RMS (OSE)	RMS (OSE)	RMS (OSE)

ORBITER-SUPPLIED EQUIPMENT (OSE)

Figure 2-16. Tug Support System Concepts - Operational Comparison

The rotating deployment adapter concept was originally devised in an effort to provide Tug system autonomy, ease of maintenance and checkout, and simplified payload and Tug changeout. Its operational comparison with alternative support/deployment techniques shows that the deployment adapter technique:

a. Establishes RF communication before disconnecting electrical umbilicals, which include hardwire safety monitoring functions.

b. Precisely guides Tug in and out of the cargo bay when side clearance is small.

c. Enables complete system checkout of in-flight functioning umbilicals before installation in the cargo bay.

d. Requires modification of aft Y fitting to permit rotation.

The lateral deployment with RMS concept eliminates the cylindrical deployment adapter, its associated mechanisms, and position control features. This technique:

a. Has fewer mechanisms (umbilical panel actuators only).

b. Provides no additional docking alignment capability (Orbiter supplied latch guides are used). Close clearance control is required along the full length of Tug and its payload to prevent interference with the Orbiter longeron, i.e., no Orbiter impact protection.

c. Umbilical mating and compatibility checks must be accomplished in the cargo bay.

d. No communications capability during cargo bay removal/insertion.

The rotation aid concept has peripheral equipment similar to the lateral deployment scheme but employs a revised operations technique to provide improved position control. The rotation aid approach:

a. Employs mechanisms for umbilical panel actuation only.

b. Improves docking clearance slightly by mating aft support points first (Orbiter latch guides constitute only positive alignment device), i.e., no Orbiter impact protection.

c. Requires in-bay umbilical mating and compatibility checks.

d. Has communications deadband during deployment/retrieval.

e. Requires modification of aft Y fitting to permit rotation.

The rollout with arms concept uses special Orbiter-supplied mechanisms to supply positive Tug positioning during removal and insertion in the cargo bay. This technique:

a. Substitutes Orbiter-supplied mechanisms/controls for Tug peripheral equipment mounted in the deployment adapter.

b. Uses two actuation arms to provide precise predetermined motion of cargo into and out of cargo bay.

c. Positions docking alignment cones (2) and probes remote from Orbiter, minimizing possibility of cargo-to-Orbiter impact.

d. Position of probe-cone during docking is near optimum for manipulator operator direct vision.

e. Actuation arm mechanism must provide an additional vertical initial motion to disengage Y fitting, or Y fitting must be reconfigured to allow lateral movement during Tug deployment/retrieval.

f. Requires in-bay umbilical mating and compatibility checks.

g. Has a communications deadband during deployment/retrieval.

2.2.2 SAFETY COMPARISON. Each of the four interface system concepts was compared for hazards associated with communications deadband, insertion/removal damage, and backup capability. The results of this comparison are shown in Figure 2-17.

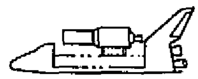
HAZARD	ADAPTER 	LATERAL W/RMS 	ROTATE W/RMS 	ROLLOUT W/ARMS 
DEADBAND IN COMMUNICATION AT HANDOFF	HARDWIRE SAFETY HARNESS ROTATES WITH ADAPTER (EASY CONVERSION TO RF COMM)	HARDWIRE SAFETY HARNESS IMPRACTICAL	HARDWIRE SAFETY HARNESS IMPRACTICAL	HARDWIRE SAFETY HARNESS IMPRACTICAL
POTENTIAL STRUCTURAL DAMAGE TO ORBITER WHILE MANUEVERING IN BAY	ADAPTER WOULD RECEIVE SHOCK LOADS	PROXIMITY TO STRUCTURE	LESS THAN LATERAL CONCEPT	ARMS DOCKING POSITION AWAY FROM ORBITER
INABILITY TO CLOSE ORBITER DOORS	RMS BACKUP AVAILABLE AFTER ADAPTER LATCHED TO TUG; MECHANICAL REDUNDANCY IN ADAPTER LATCHES AND DRIVE SYSTEM.	RESORT TO EVA AND/OR RELEASE & USE RMS	RESORT TO EVA AND/OR RELEASE & USE RMS	RMS BACKUP AVAILABLE AFTER TUG ATTACHED TO ARMS

Figure 2-17. Tug Support Systems Concepts - Safety Comparison

The most significant hazard to be contended with is the gap in communication of safety monitor data. Only the deployment adapter concept supplies the capability of maintaining hardware caution and warning communications data until Tug is suitably positioned for RF link establishment. The three alternative concepts do not contain a suitable mounting location or position control structure for electrical panel mounting. Trailing umbilicals were briefly investigated for deployment hardware maintenance but were rejected due to potential stowage problems and lack of suitability during retrieval. A small electrical connector could be mounted in one of the arm docking drogues, but the present JSC concept does not include this capability.

Both the deployment adapter and arms concepts provide assurance that a Tug-Orbiter collision will not occur. The D/A provides rough alignment capability (6 in.; 15 cm radial) and a positive stop to restrain Tug movement toward the Orbiter 1307 bulkhead. Tug attachment to arms occurs sufficiently far from surrounding Orbiter structure to preclude inadvertent impact (see Figure 2-14). The two concepts using RMS for Tug payload bay removal provide little margin for handling error.

Since the lateral and position aid concepts use RMS motive force and control to effect all portions of deployment/retrieval, no mechanical backup device is available should something go wrong (longeron latch hangup in its closed position during retrieval, for example). With the D/A or arms concepts, once Tug-to-adapter or Tug-to-arms latching is accomplished, the RMS is available for backup repairs (latch freeing). Since the other concepts must use RMS for the entire retrieval sequence, Tug must either be released to free RMS, or EVA must be used for the backup repair job.

2.2.3 WEIGHT/PERFORMANCE COMPARISON. The Tug deployment mission payload performance penalty for the four Tug/Orbiter interface support concepts is summarized in the lower block of Table 2-5. Weight details used to arrive at these payload effects are shown in the body of the table. The "Direct Lateral" columns apply to both the RMS deployment and rollout with arms deployment techniques. Weight for the arms (which are assumed to be Orbiter chargeable) is not included.

Using the adapter support with rotational deployment as the base, weight calculations indicate that the direct support concept with lateral or arms deployment will degrade the overall Tug system's geosynchronous payload delivery capability by 48 lb (22 kg). The direct support with rotational deployment results in a payload gain of approximately 113 lb (51 kg). This indicates that weight is not really a major discriminator in determining which support/deployment concept is best. The payload weight partials used in developing these estimates are:

For Tug vehicle items:	-2.62 lb (kg) payload = +1.00 lb (kg) vehicle weight
For Orbiter-retained items:	+0.38 lb (kg) payload = -1.00 lb (kg) Orbiter-retained weight

The payload weight differences are based on the comparative Δ weights shown in the upper part of the chart. Only the weights of affected interface items are included. This comparison indicates that as far as the Tug vehicle itself is concerned, it is lightest when the adapter is used. This is because three Orbiter attachment fittings and adjacent structure are removed from Tug structure and transferred to the deployment adapter assembly. The weight advantage of using the adapter concept with the Tug vehicle, however, is almost entirely lost since the added weight of the adapter and surrounding equipment are substantial.

2.2.4 COST COMPARISON. Table 2-6 presents cost differences for alternative support/deployment methods, relative to the deployment adapter rotation concept, which was used as reference baseline. The direct lateral support deployment concept (for both RMS and rollout with ARMS) gives an approximate 87 thousand dollar DDT&E reduction. The direct rotational concept is about 760 thousand dollars below the DDT&E cost of the baseline concept. The primary cost differences are due to the deletion of the adapter structure and mechanisms which are part of the baseline concept.

Table 2-5. Tug Support System Concepts — Weight/Performance Comparison

	Tug Vehicle			Orbiter Interface Equip		
Support Method → / Deploy. Method →	Adapter Rotation	Direct Lateral	Direct Rotation	Adapter Rotation	Direct Lateral	Direct Rotation
Structure & Mech Δ Wt (lb)						
Body Shell	722	820	820			
Adapter Shell				482		
Truss Support				70	204	204
Orbiter Attach Fittings	22	130	130	108		
Rotation Mech				40		
Latch Mech				170		
Fluid Systems Δ Wt (lb)						
GO_2 Vent	71	72	71	10	15	14
LO_2 Fill, Drain & Dump	66	71	66	35	51	46
LO_2 Topping	7	9	7	11	20	17
GH_2 Vent	120	123	120	55	79	71
LH_2 Fill, Drain & Dump	240	272	240	82	185	122
Helium Supply & System	105	107	105	490	513	506
Umbilical Panels	26	28	26	52	52	52
Supports & Misc	15	17	15	22	22	22
Electrical & Avionics Δ Wt (lb)						
Avionic Interface Unit				50	50	50
Electrical Panels	20			36	24	24
Wiring & Connectors	134			164	230	230
Supports & Misc	20			23	23	23
Total Δ Wt, lb (kg)	1, 568 (711)	1, 649 (748)	1, 600 (726)	1, 900 (862)	1, 468 (666)	1, 381 (627)
Comparative Δ Wt, lb (kg)	Base	+81 (+37)	+32 (+15)	Base	-432 (-196)	-519 (-235)
Δ Payload Wt (Geosyn Delivery), lb (kg)	Base	-212 (-96)	-84 (+38)	Base	+164 (+74)	+197 (+89)

Net Payload Weight Effect:

With adapter, Rotation Deployment	=	Base (lb)	Base (kg)
W/O adapter, Lateral Deployment	=	-48	(-22)
W/O Adapter, Rotation Deployment	=	+113	(+51)

Table 2-6. Tug Support Systems Concepts Cost Comparison

	DDT&E Δ Cost ($M)		
Concept/Subsystem	Tug	Interface	Total
Deployment Adapter	Reference Baseline		
Direct Lateral			
Structure/Mech	+0.826	-1.557	-0.731
Fluids	+0.438	+0.849	+1.287
Electrical	-0.884	+0.415	-0.469
	Total Δ Cost		-0.087
Direct Rotational			
Structure	+0.826	-1.557	-0.731
Fluids	—	+0.439	+0.439
Electrical	-0.884	-0.415	-0.469
	Total Δ Cost		-0.761

2.3 FORWARD UMBILICAL PANEL

Work performed in the payload Orbiter services accommodations trade study (Section 3, Volume II) indicated the desirability of providing a standard Orbiter to forward Tug umbilical panel for payload services. In the mechanical interface subsystem trades (Section 4.3, Volume II) means of providing this forward interface were investigated. This section summarizes the work accomplished during the interface compatibility study on forward umbilical panels, assesses their desirability from a total interface system standpoint, and provides a recommendation.

2.3.1 PAYLOAD SERVICES ANALYSIS RESULTS. Electrical and fluid services are required for Tug payloads from the Tug and also from the Orbiter/Ground. The Tug to payload services must be routed through the payload adapter. Payload to Orbiter/Ground services have three routing options: 1) through the deployment adapter, Tug, then to payload, 2) direct from Orbiter to payload, or 3) through a Tug forward panel to the payload, as illustrated in Figure 2-18. Since all payloads must attach to the Tug at the payload adapter interface, a common umbilical interface can easily be provided. For multiple Tug payloads, and different diameter payloads, providing umbilicals directly from the Orbiter would require many unique design configurations, which would be cost prohibitive and in conflict with the Space Shuttle System

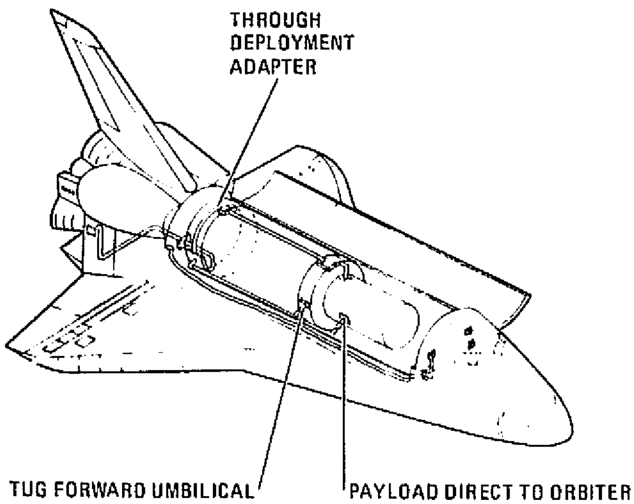


Figure 2-18. Payload Umbilical Options

concept general philosophy. Due to this consideration, direct routing was not considered a candidate and was eliminated from contention. The payload services identified for possible forward umbilical panel routing are shown in Table 2-7.

New Tug payloads conceived and designed specifically for use with Shuttle may have additional service functions, which could benefit from forward umbilical routing. Because the preceding payload service investigation for Tug indicated that a forward-mounted Orbiter-to-Tug umbilical panel was desirable for Tug payloads, other Orbiter payloads were reviewed for forward umbilical panel

Table 2-7. Potential Payload Forward Umbilical Service Functions

Payload Function	Service Level
Prop Abort Dump Vent	>> 500 lb (250 kg) ~ 0.5 in. (1.27 cm) dia each prop
LHe F&D	~ 1.0 in. dia (2.54 cm)
Shroud Conditioning	~ 3.0 in. (7.62 cm) dia class < 5000 GN_2

applicability. Figure 2-19 depicts multiple payload installation in conjunction with Orbiter maneuvering system (OMS) kits. Generally, non-Tug payloads require umbilicals throughout the cargo pay to provide for multiple payload installations, disconnect function for deployed payloads, and reconnect function for retrieved or serviced payloads. Existing Orbiter panels located on the bulkheads may be relatively inaccessible due to OMS kits or other payloads and do not provide disconnect/reconnect mechanisms.

2.3.2 FORWARD PANEL JUSTIFICATION. The alternative routing for potential forward umbilical services is through Tug. A comparative analysis was conducted for two concepts, as shown in Figure 2-20. Table 2-8 summarizes the comparative weight, line routing, and operational flexibility data for the two payload umbilical panel locations. In addition to payload use of the forward umbilical panel, the Tug avionics

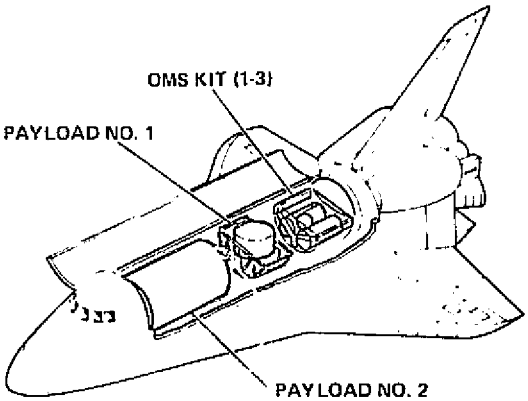


Figure 2-19. Typical Multiple Non-Tug Payload Installation

are mostly located in the Tug forward end and can use the forward panel to advantage. As shown in this analysis, considerable benefits are potentially available if a forward umbilical panel is available for payload use.

2.3.3 FORWARD PANEL IMPLEMENTATION CONSIDERATIONS. The design requirements for a forward umbilical are similar to an aft mounted panel, including static and dynamic misalignment capability, load capability for pressure separation forces, realignment guides to enable remate engagement, and disconnect motion by an actuator system. The major single difference is the longitudinal Orbiter X_0 position. To accommodate both Tug and non-Tug payloads throughout the cargo bay, nine locations for intermediate umbilical panels are recommended. These are positioned 9.83 inches (25 cm) aft of the support locations as shown in Figure 2-21.

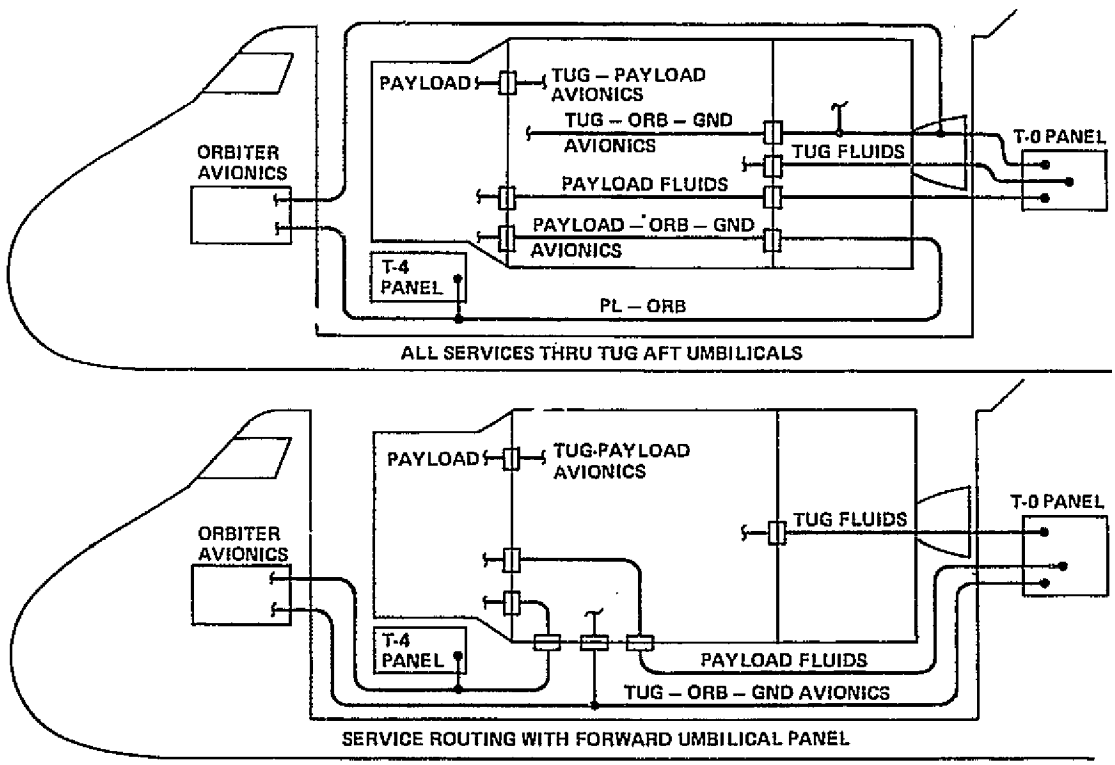


Figure 2-20. Umbilical Routing Comparison for Tug Payloads

Table 2-8. Payload Umbilical Comparison

Consideration	Forward Umbilical		Via Tug Aft Umbilical	
	Orbiter	Tug	Orbiter	Tug
Struct/Mech Wt, lb (kg)	100 (45)	25 (11)	10 (4.5)	8 (3.6)
Fluid Services Wt, lb (kg)	135 (61) (18 active disconnects)	20 (9)	61 (28) (24 active disconnects)	163 (74)
Elect Services Wt, lb (kg)	37 (17) (60 noncritical lines)	15 (7)	143 (65) (60 noncritical lines)	73 (33)
Total P/L Penalty, lb (kg)	260 (118)		718 (326)	
Line Routing Small < 1 in. (2.5 cm) dia.	Thru cargo bay raceways		Between Tug tank and shell	
Large > 1 in (2.5 cm) dia.	Outside cargo bay envelope		Not allowed	
Operational Simplicity and Flexibility	Single forward location satisfies all Tug payload reqt and also accommodates non-Tug payloads. Common interface location simplifies Orbiter design, installation and service reqt.		Different kit required for non-Tug payloads, possibly different/added kit for various Tug payloads. Different kits may require different GSE and added operations tasks.	

Three circumferential locations, shown in Figure 2-22, were considered for positioning the forward umbilical panels in the Orbiter cargo bay. The recommended location is a compromise of the factors compared in Table 2-9. The significant advantage of each location is 1) the longeron location is readily visible, 2) the keel position uses existing support points, and 3) the intermediate position gives good line routing without interfering with the crawlway space. The intermediate location at Orbiter Y_0 Station-30 inches (-76 cm) was chosen based mainly on the advantages gained by cable/tube routing and redundant disconnect operation. These factors

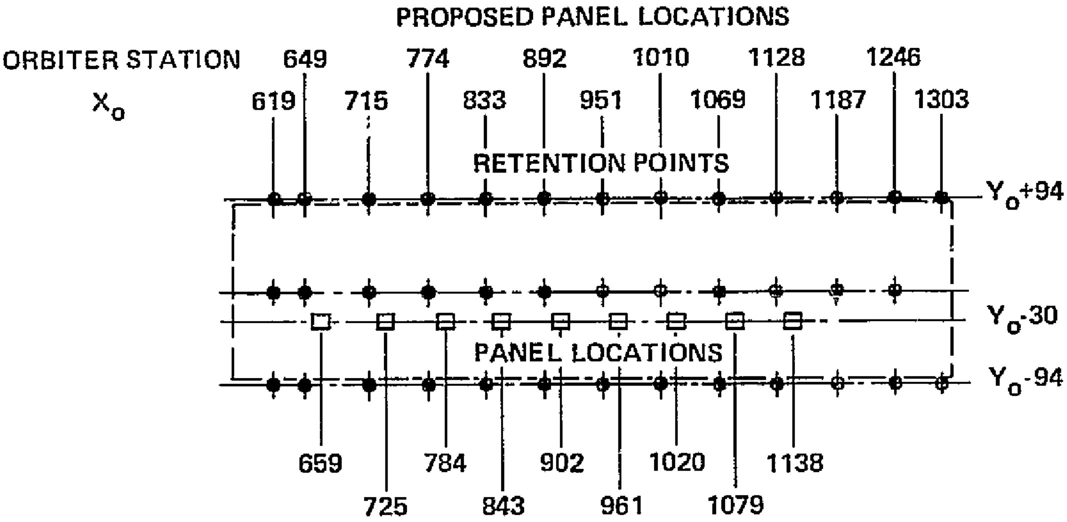


Figure 2-21. Recommended Panel Locations

reduced installation complexity and increased the chance of mission success respectively. The weight of the forward umbilical panel would be chargeable to the Tug peripheral equipment or to each non-Tug payload for which a panel is installed.

2.3.4 RECOMMENDATIONS. The following conclusions were reached regarding the desirability of an Orbiter supplied cargo bay umbilical panel system:

a. Spacecraft require a unique number and size of fluid and electrical Orbiter connectors.

b. A forward umbilical panel on Tug can be used with easily accessible spacecraft unique fluid and wiring kits.

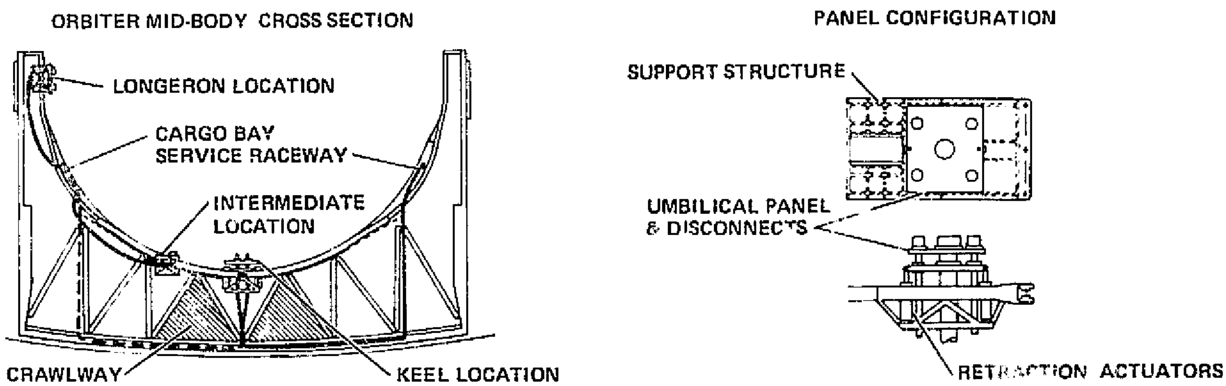


Figure 2-22. Forward Umbilical Panel

Table 2-9. Panel Location Comparison

Comparison Factor	Longeron	Keel	Intermediate
Installation	New Orbiter support points required. Installation depth questioned	Mounts from modified keel bridge beam to existing Orbiter support points	New Orbiter support points required
Cable/Tube Routing	Short route to service raceway	Routing around crawlway is difficult	Short route to service raceway
Access	Umbilicals are visible via RMS TV for inspection	Visual inspection not possible	Visual inspection not possible
Disconnect Operation	Jammed umbilical panel prevents deployment	Payload will separate if panel fails to retract	Payload will separate if panel fails to retract
EVA Assist	Possible due to location	Not possible	Not possible

c. Tug avionics are mostly located at the Tug forward end; therefore Tug wiring and weight can be minimized by using the forward umbilical for Tug functions other than caution and warning.

d. Other non-Tug payloads need retractable/reengageable umbilical services for deployment, retrieval, and servicing missions.

The incorporation of an Orbiter to payload umbilical panel similar to that presented here is recommended.

2.4 INTERFACE SYSTEM SELECTION

Based on the Tug support/deployment system comparisons identified in Section 2.2 for the interface concepts defined in Section 2.1, a composite evaluation was accomplished to select the best interface system. The number of system candidates subjected to this final comparison was reduced to three by elimination of lateral

deployment with RMS. This concept is similar to the lateral roll-out with arms technique in all respects except for a serious lack of any positive positioning control.

The seven evaluation parameters, associated assessments for each of the three remaining candidates, and the recommended interface concept selected are presented in Figure 2-23.

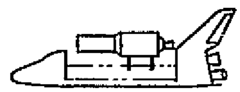
EVALUATION PARAMETER	ADAPTER 	LATERAL ROLLOUT 	ROTATE W/RMS 
DEPLOYMENT DEVICE	D/A – RMS	PIVOT ARMS – RMS	RMS
CLEARANCE CONTROL	VERY GOOD	BEST	MARGINAL
C&W FUNCTIONS	NO DEADBAND	DEADBAND	DEADBAND
UMBILICAL ALIGNMENT	BEST	ADEQUATE	ADEQUATE
OPERATIONAL SIMPLICITY	VERY GOOD	ADEQUATE	POOR
TUG PERFORMANCE	REFERENCE	-48 LB (-22 KG)	+113 LB (+51 KG)
I/F EQUIP COST	REFERENCE	-$0.087M	-$0.761M
RECOMMENDATION	SELECTED		

Figure 2-23. System Assessment of Tug/Orbiter Support/Deployment Methods

The adapter and pivot arm deployment/alignment techniques provide the best Tug/Orbiter clearance control. Additionally, the adapter provides a positive guard against structural interference of the Tug engine and aft cargo bay bulkhead during retrieval operations when Tug is RMS inserted back into the Orbiter. The deployment adapter concept eliminates the gap in communication of safety monitor data. Hardwires are maintained through rotation until RF communication can be established. The close coupling of Tug and adapter provide better umbilical alignment than floating Tug-to-Orbiter connections.

Operationally, the rotating deployment adapter provides Tug system autonomy, ease of maintenance and checkout, simplifies Tug changeout, and improves interface verification by enabling a complete system checkout of in-flight functioning umbilicals before installation in the cargo bay. A small geosynchronous delivery performance difference exists for the three concepts.

The primary cost differences are due to the deletion of the structure and mechanisms that are part of the deployment adapter. The result of the deployment/support system

trade was the recommended retention of a deployment adapter concept very similar to that used with the MSFC baseline Tug. The overriding selection criteria were operational flexibility and safety rather than performance or cost considerations.

After completion of the interface system selection, revisions were made to the configuration and operation of the selected deployment adapter concept. These revisions resulted from additional technical work performed late in the study effort as special emphasis tasks. Details of the work accomplished are included within each major system oriented subsection of Section 4, Volume II.

The revisions made to the deployment adapter support/deployment concept are summarized in the following paragraphs. A more complete definition of the reco...nended interface equipment configuration is contained in Section 4 of this volume. These changes are interface implementation improvements that additionally strengthen selection of the deployment adapter concept. Deployment adapter configuration and support concept changes identified below are in reference to the concept description contained in Section 2.1.1.

Instead of the four- or five-point support systems previously considered for Tug plus its deployment adapter, the six-point doubly redundant (in Z and Y direction) configuration depicted in Figure 2-24 was recommended. The three aft supports (two X/Z and one Y) are located on the Tug deployment adapter (D/A). The D/A cylindrical structure provides distribution of the point axial (X) Orbiter support loads into the Tug shell, and serves as a convenient mounting location for other support/servicing equipment including umbilical panels, dump pressurization, and interface electronics.

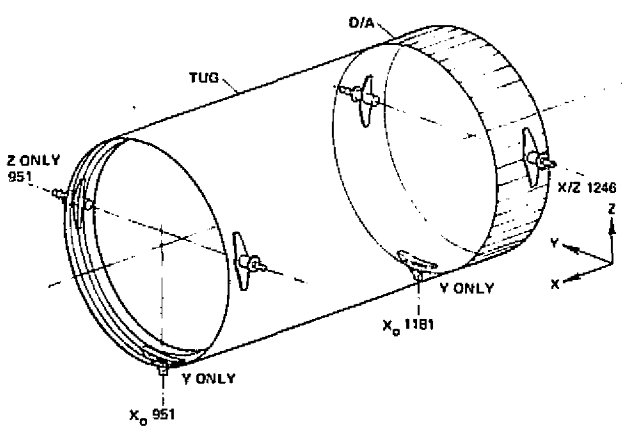


Figure 2-24. Recommended Tug Support System

The major evaluation criteria used in the selection process were: Tug Δ-weight and Δ-payload capability, Tug/Orbiter clearance loss due to Tug dynamic response, and support reaction compatibility with Orbiter capability. The selected configuration is compatible with Orbiter capability; it uses all existing primary support locations, and no reactions (including crash) exceed Orbiter capability for MSFC-developed payload/Orbiter accelerations. The six-point redundant support system is best for Tug; it results in low Tug body loads, least deflection (0.2 in. (0.5 cm) at X_0 936), least dynamic response, and excellent Tug performance.

Deployment adapter revisions included deletion of the fluid umbilical panel retraction operation before rotation and elimination of the support truss and its requirement for a special keel bridge beam attachment. The new deployment adapter configuration is shown in Figure 2-25.

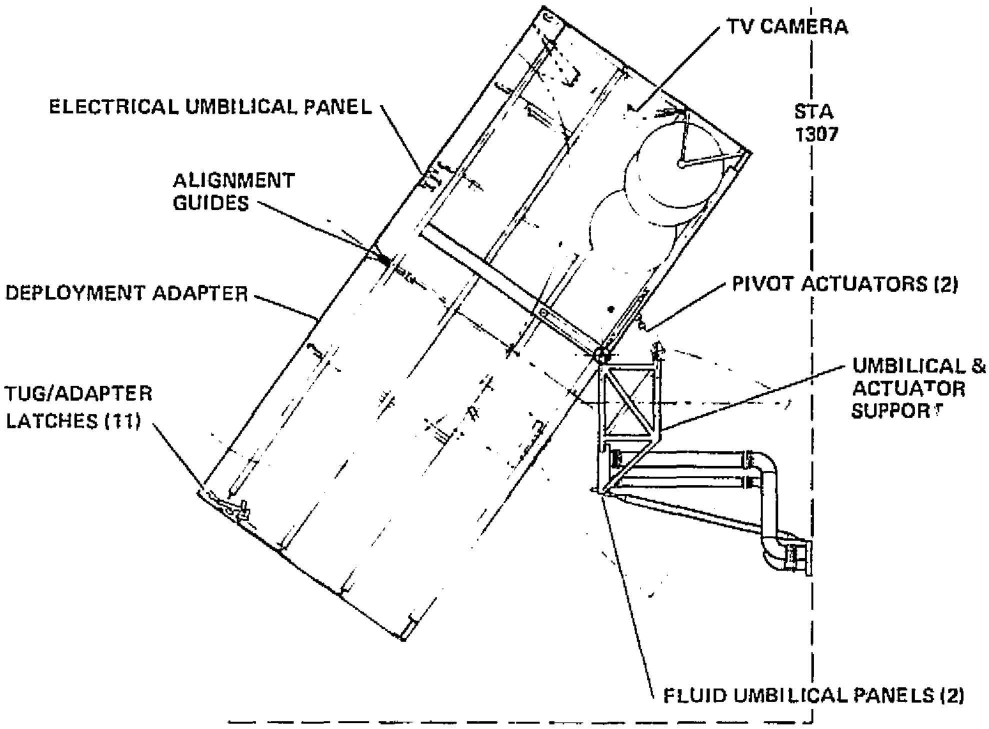


Figure 2-25. Recommended Deployment Adapter Mechanisms

Refinement of design replaced the large support truss with two small umbilical panel supports. The supports are pivot mounted to the deployment adapter, concentric with the station 1246 support. Umbilical separation forces are reacted through the pivot and also through a strut attached to the station 1307 fluid interface panels. Umbilical misalignments are enabled by limited travel bellows at each disconnect.

The fuel umbilical support incorporates attachments to mount the adapter pivot actuators. The forces exerted on the deployment adapter by the pivot actuators are sufficient to disconnect and reconnect the umbilicals. The large moment arm to the forward umbilical panel prevents the pivot actuators from reliably disconnecting the forward umbilicals therefore requiring their separation before rotation.

The Tug-adapter latches are essentially the same over-center mechanism presented in the NASA baseline Tug with the exception of a cam face to actively separate the Tug from the adapter. This latch separation force is used to disengage shear pins and the

C&W electrical umbilical. The quantity of latches has been reduced from 16 to 11. This was done since loads carried by these deleted latches were negligible.

An Orbiter-supplied TV camera is located in the deployment adapter to provide monitoring of alignment during deployment and retrieval. The TV views a target on the Tug. The Tug umbilical panel supports and the target supports are designed to provide mechanical centering and guidance of the Tug. An offset of approximately 10 in. (25.4 cm) can be accommodated. Progressive terminal alignment is provided by the latch mechanism and shear pins.

As mentioned, a forward umbilical panel for Tug payload services is included as part of the recommended interface concept. Although Tug services do not justify the use of this panel, Tug payload fluid service requirements do. The incorporation of a forward umbilical panel between Orbiter and Tug will provide excellant flexibility in payload service requirements satisfaction, and eliminate costly development and operational impacts associated with payload-peculiar support equipment in the cargo bay. Section 2.3 provides additional forward umbilical panel details and recommendations.

SECTION 3

INTERFACE DEFINITIONS OPERATIONAL DESCRIPTION

The best method of describing the complete range of physical and operational interfaces between Tug plus its payload and the Orbiter is through a recommended operational scenario. The text and figures in this section describe the selected operations plan upon which the recommended interface implementation and proposed Orbiter accommodations revisions are based. The operations discussed are limited to those associated with Tug attached or in close proximity to the Orbiter, as bounded by the scope of this study. The recommended Tug six-point redundant support, deployment adapter mounting concept described in Section 2.4 is used for this operational interface definition.

Tug plus Tug payload to Orbiter interfaces are associated with Shuttle operations from installation through landing and safing, as shown in Figure 3-1. Each of these operational phases is investigated to develop a time-phased definition of Tug/Orbiter interface activity and interaction.

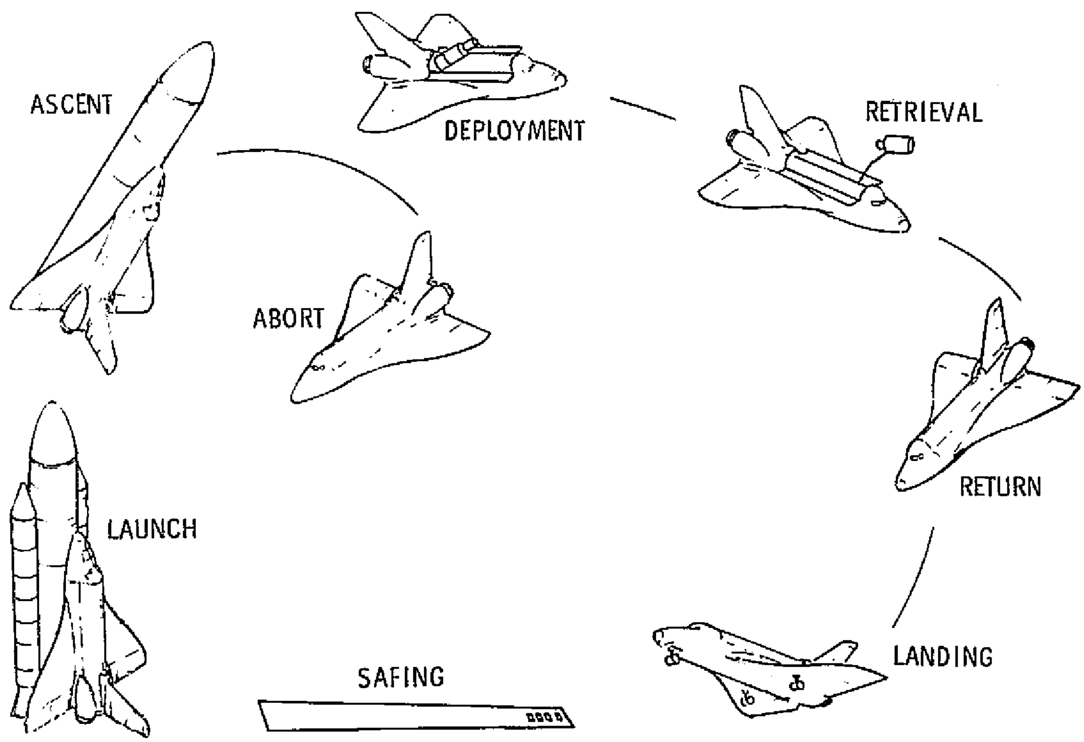


Figure 3-1. Tug and Payload-to-Orbiter Operational Interface Phases

3.1 PRELAUNCH OPERATIONS

Tug interface related prelaunch operations consist of Orbiter preparation, Tug/payload installation, and prelaunch conditioning and tanking.

3.1.1 <u>ORBITER PREPARATION.</u> The initial preflight operational involvement of the Tug with the Orbiter occurs with the installation of unattached Tug peripheral equipment. This equipment is required for Tug support in the Orbiter but is installed before and separately from the Tug. It includes service connections, structural support fittings, and Tug-unique cargo bay umbilical panels and equipment located in the Orbiter crew compartment. The location of these items is shown in Figure 3-2.

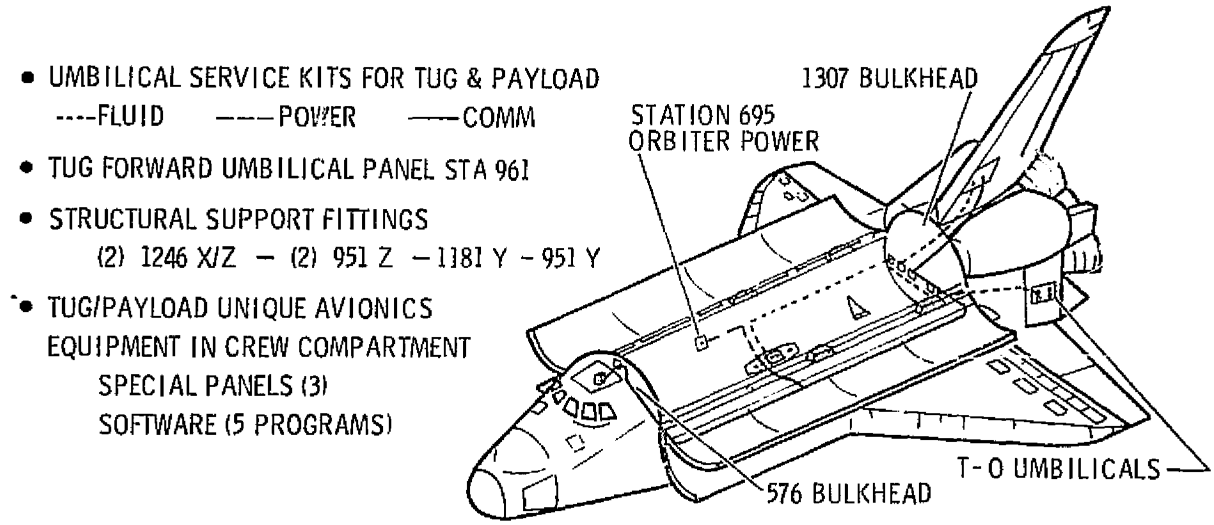


Figure 3-2. Orbiter Preparation for Tug and Payload

<u>Umbilical Service Kits for Tug and Payload.</u> The current Orbiter philosophy reflects complete Orbiter control of service lines running from station 1307 panels to T-0 or aft firewall panels, through the engine compartment. As such, these service lines are not Tug kits and are not included in the peripheral equipment category, although requirements generation remains a Tug responsibility. Service panel adapter plates and service transmission lines within the cargo bay are Tug peripheral equipment items installed at this time. Internal service line routing is through the Orbiter-provided raceways located on either side of the cargo bay. Service lines connect the station 576 forward bulkhead communications panel, station 695 power distribution panel, and station 1307 aft bulkhead panels with the Tug once it is installed.

<u>Forward Umbilical Panel.</u> A special umbilical panel located at the forward portion of the Tug structural shell has been proposed to provide improved payload operational flexibility. The Orbiter mounted, active half of this panel is installed like a keel

bridge beam with the provided Orbiter attachments. Service line routing between the panel and the raceways lies outside the cargo bay envelope beneath the liner.

Structural Support Fittings. Orbiter bridge beams and fittings are installed to structurally support the Tug. Included are the two primary X/Z fittings at station 1246 (not normally released during Tug deployment), the Y fittings at stations 1181 and 951, and two Z remote latching fittings at station 951.

Crew Compartment Equipment. The Space Tug makes maximum use of standard Orbiter equipment supplied for payloads to reduce costs and simplify interfaces and operations. Three special Tug control panels including switches and status lights are installed in Orbiter-provided consoles, two in the mission specialist station and one in the payload handler station, along with wiring connecting the three panels with the Orbiter-supplied payload MDM. Software programs are loaded into the Orbiter-supplied computer and ground checked.

Orbiter interface provisions for fluid and electrical umbilical connections are described in Table 3-1. This table indicates interface size, service function, and its point-to-point through Orbiter routing. Possible arrangement of these functions on the cargo bay service and T-0 launch umbilical panels are depicted in Figure 3-3. The line numbers indicated on the interface panels correspond with the interface identification numbers used in Table 3-1.

3.1.2 TUG/PAYLOAD INSTALLATION. The Tug is installed in the Orbiter payload bay with its deployment adapter-to-Tug interface and payload-to-Tug interface completely checked out and verified. The only consumables aboard the Tug during installation are APS propellants (N_2H_4) and helium supply at half flight pressure. The payload storable propellant(s) is also onboard. Ground power is supplied for Tug and payload safety monitoring via a deployment adapter mounted connector during installation.

Tug (plus deployment adapter and payload) can be Orbiter installed either horizontally or vertically. Vertical installation is preferred and illustrated in Figure 3-4. Tug plus deployment adapter is configured as shown; main engine nozzle fully retracted and umbilical panel supports restrained (by rotation actuators for the LH_2 panel and a special remote-before-flight latch for the LO_2 panel) in their Tug mated position.

Handling (either vertically or horizontally) is accomplished by connecting suitable slings or installation fixtures directly to the Tug and D/A primary support fitting hubs inboard of the cargo bay attachment bearing/sliders. With the Orbiter fitting guides retracted or removed (these guides are not designed for 1 g handling loads), the Tug is gently placed into bay, the structural support fittings mated, and latched. Keel attachments are probes that mate with receptacles in the Orbiter keel fittings; no active latching is required.

Table 3-1. Fluid/Electrical Umbilical Interfaces

1307 Panel Number	Line Dia (in)	Service Function	Exit Location	No.
1	4.0	LO_2 Fill, Drain, & Abort Dump	T-0 Oxidizer	1
2	2.0	GO_2 Positive and Zero G Vent	Orbiter Skin	-
3	0.75	LO_2 Topping Line	T-0 Oxidizer	3
4	0.75	GHe Vent - Oxygen Tank Insulation LCM	T-0 Oxidizer	4
5	0.50	H_2O RTG Cooling Inlet	T-0 Oxidizer	5
6	0.50	H_2O RTG Cooling Outlet	T-0 Oxidizer	6
7	3.0	Steam Vent - RTG Cooling	Firewall	-
8	5.0	LH_2 Fill, Drain & Abort Dump	T-0 Fuel	8
9	3.0	GH_2 Ground Vent	T-0 Fuel	9
10	2.5	GH_2 Flight Relief	Vert Fin	-
11	0.75	GHe Vent LH_2 Tank Insul LCM	T-0 Fuel	11
12	0.38	Helium Supply	T-0 Fuel	12
-	0.5	N_2H_4 APS Relief	535 Panel	-
13	-	Elec. Grnd Monitor & Control	T-0 Oxidizer	13
14	-	Elect. Crew Monitor & Control	576 Bulkhead	14
15	-	Elec. Grnd Monitor & Control	T-0 Fuel	15

Once the Tug is structurally attached to the Orbiter and the installation fixture removed, umbilicals are connected. The forward keel umbilical is remotely engaged and checked for electrical continuity. The aft umbilicals are manually engaged by adjusting the support struts. After the panels are positively engaged, the LO_2 panel installation latch is removed and leak tests and continuity checks are performed. Access to these panels is restricted but feasible. Suitable ground-supplied platforms will be needed to obtain the required accessibility.

3.1.3 PRELAUNCH CONDITIONING AND TANKING. After Tug physical installation and umbilical attachment, the Tug, deployment adapter, spacecraft and Orbiter are subjected to an Orbiter integrated test (OIT) and a launch readiness verification (LRV) to verify the proper integration of the vehicles' monitor and control functions. Following successful completion of LRV, the Tug vehicle remains under ground standby control until just before propellant tanking.

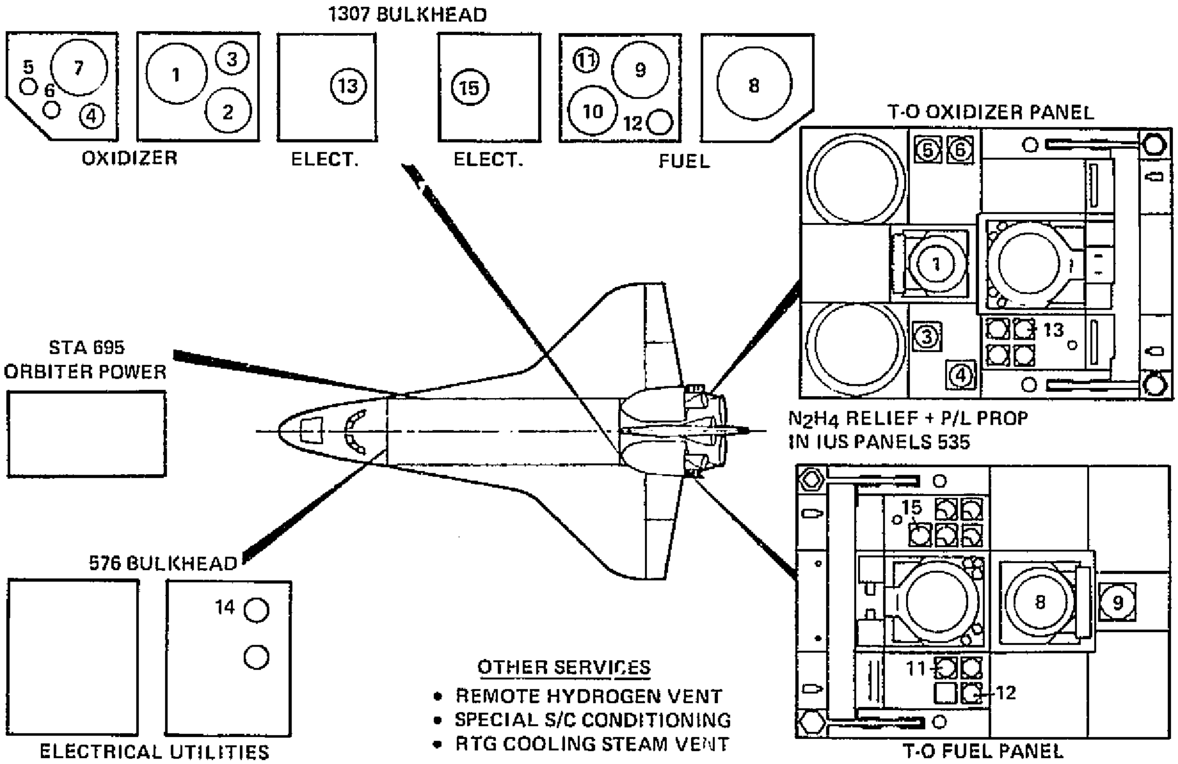


Figure 3-3. Tug Service Panel Umbilical Arrangement

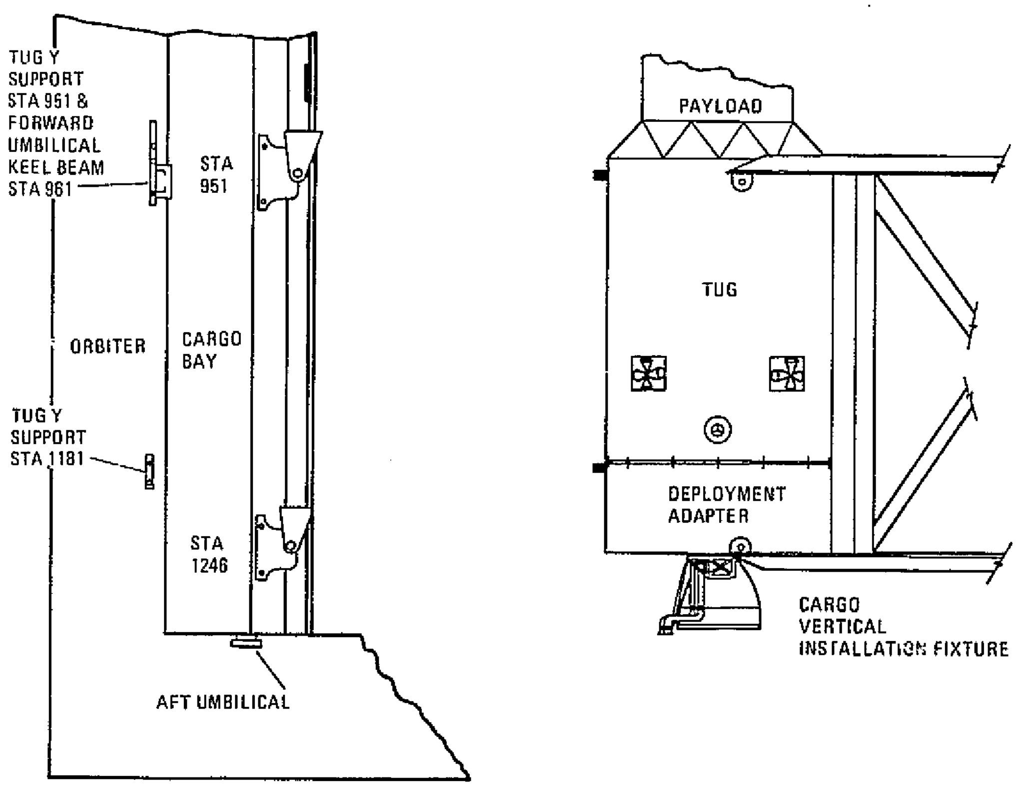


Figure 3-4. Tug/Payload Installation

The Shuttle Orbiter ET propellant loading sequence shows a total load time of 75 minutes from initiation of countdown at T-120 minutes to fast-fill cutoff of both LO_2 and LH_2 at T-45 minutes. At this point, the Shuttle external hydrogen and oxygen tanks are 98.5 percent full; crew boarding begins while the tanks are being brought up to 100 percent with the propellant replenish systems. Tug loading of LO_2 and LH_2 is accomplished concurrently with ET.

GN_2 cargo bay conditioning and Tug helium purges are initiated at T-135, and tanking occurs from T-120 to T-60 minutes. Tug cryogenic propellant replenishment is terminated 7.5 seconds before liftoff, followed by Shuttle ignition and liftoff.

Propellant tank venting is accomplished via the T-0 fuel panel to a remote burn stack for hydrogen, and to atmosphere at the Orbiter mold line for oxygen. During the final 60 minute countdown, the Tug and D/A helium supply is increased to flight pressure and the Tug fuel cells are started.

Figure 3-5 shows the T-0 fuel side ground umbilical (oxidizer T-0 on opposite side is similar) and depicts the prelaunch conditioning GN_2 flow. Prelaunch status of Tug fluid and electrical services is listed.

- APS N_2H_4 & PAYLOAD STORABLE PROPELLANT(S) LOADED BEFORE ORBITER INSTALLATION
- PRELAUNCH CONDITIONING
  - MINIMUM OF 140 LB/MIN DRY GN_2
  - 64 ±5F INLET -76F DEW POINT EXHAUST AT CARGO BAY AFT END
- TUG PROPELLANT LOADING PURGES
  - LEAKAGE CONTAINMENT MEMBRANE
  - MULTILAYER INSULATION
  - UMBILICAL PANELS
- PROPELLANT TANKING
  - CONCURRENT WITH ET TANKING
  - WITHIN ONE HOUR + REPLENISH
- TUG ON GROUND POWER & CONTROL
- TUG SYSTEMS SAFED
  - DEPLOYMENT ADAPTER
  - SPACECRAFT DEPLOYMENT
  - TUG AUXILIARY PROPULSION SYSTEM
  - TUG MAIN PROPULSION

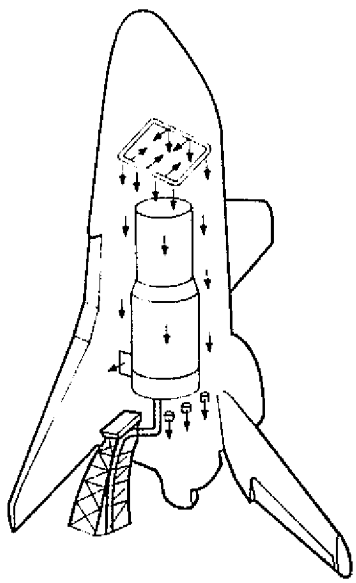


Figure 3-5. Prelaunch Conditioning and Tanking

3.2 LAUNCH AND ASCENT

During this phase of combined Tug/Orbiter operations, three important interface areas exist: caution and warning, power supply, and Tug ascent venting. Considerations associated with these interfaces are presented in Figure 3-6 and additionally described below.

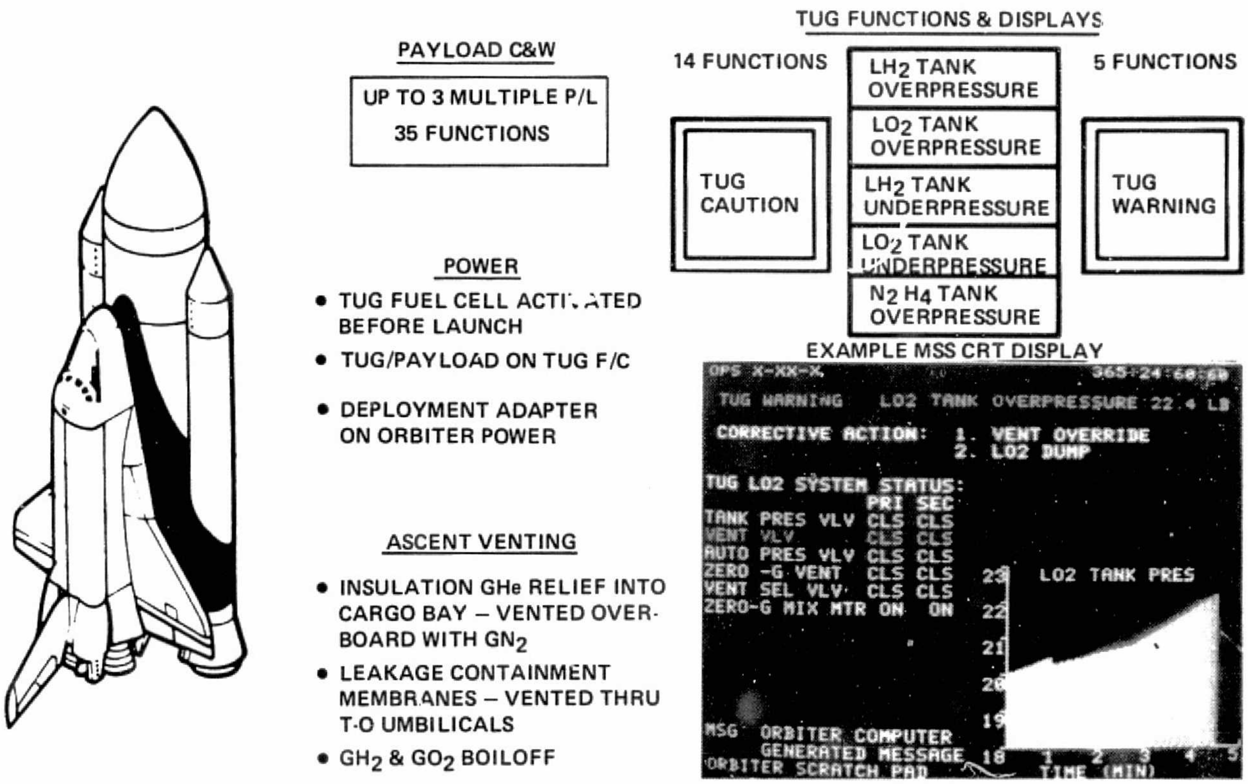


Figure 3-6. Launch and Ascent Interfaces

3.2.1 TUG AND PAYLOAD CAUTION AND WARNING. The safety of the Shuttle and the crew is ensured by three functions. First, data related to the identified Tug safety critical functions are continuously monitored and displayed through the MSS/CRT and the Tug warning panels. Second, when a safety function approaches a limit, corrective action sequences are automatically executed through Tug support software associated with the MSS equipment. Third, the monitoring system provides an alert to the crew when an out-of-tolerance condition exists, which provides adequate time for crew-implemented corrective action. Similar functions are provided for the Tug payload. The Tug warning panel has five annunciators that display safety data from three

hardwire measurements to provide immediate crew problem identification. Fourteen caution indications have been identified for Tug and its peripheral equipment:

APS ISO VLV OPEN	DEPLOY ARM/SAFE ARMED
ME ISO VLV OPEN	APS CLUSTER FAILED
TUG/ADAPTER LATCH OPEN	APS PRI ELEC FAILED
TUG/SUPPORT LATCH OPEN	APS PROP LOW
TUG/ORB DISC OPEN	H_2 IN LCM
ME ARM/SAFE ARMED	H_2 IN P/L BAY
APS ARM/SAFE ARMED	N_2H_4 IN P/L BAY

These indications are obtained from instrumentation signals transmitted through redundant multiplexed data links. Crew notification is accomplished by illumination of the master Tug caution light, and data appropriate to problem resolution is displayed on the MSS CRT. A typical example of a warning CRT display and the information that might be suitable for display is shown in Figure 3-7. A three-color presentation (red, yellow, green) is recommended to highlight critical information and aid in rapid crew evaluation and response.

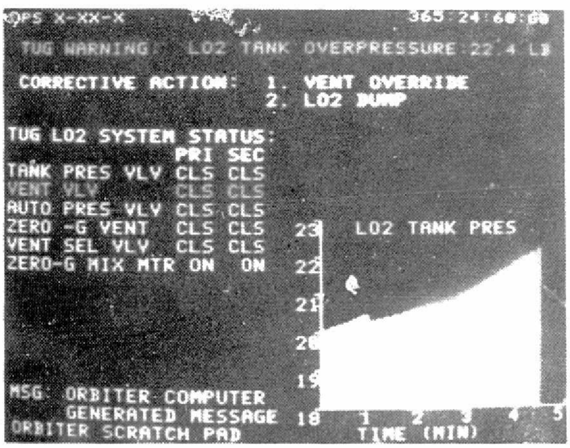


Figure 3-7. Typical CRT Warning Display with Problem Solving Information

Requirements for 35 caution and warning functions for up to three Tug multiple payloads have been identified by the payload requirements compatibility study. Crew alert, problem identification, and corrective action information would be implemented in a manner similar to that for Tug.

3.2.2 <u>POWER SUPPLY</u>. The Tug fuel cells are reactant activated and status verified during Shuttle launch countdown. Just before liftoff, Tug plus payload power is switched from Orbiter supplied to Tug fuel cell supplied, since Orbiter power available during ascent is inadequate. Tug deployment adapter power is not switched over; it is supplied from the Orbiter during the entire mission. Normally, Tug continues to supply its own plus payload power on orbit to prevent unnecessary switching. If predeployment payload checkout power demands are excessive, Tug plus payload power demand can be supplied by Orbiter since, after SSME burnout, Orbiter power availability improves. In this event Tug fuel cells remain activated until deployment with no load applied.

3.2.3 ASCENT VENTING. Tug propellant boiloff and helium purge gas is vented overboard during Orbiter ascent. This venting must not be precluded for any appreciable time period since overpressurization of propellant tankage or insulation systems could result. All vents that might contain any propellant boiloff are ducted through the Orbiter and exhausted overboard at the mold line. Helium ground conditioning gas from the propellant tank insulation systems is protected from propellant intrusion by the leakage containment membranes and is vented directly into the cargo bay. In the cargo bay it mixes with the GN_2 prelaunch conditioning gas and is exhausted overboard through the Orbiter's eight cargo bay ascent vent doors.

3.3 ABORT

A Shuttle abort may result from either a cargo or Shuttle system anomaly or malfunction. If a safety critical Tug out-of-tolerance condition is detected, a light identifying the condition is displayed on the MSS warning panel and/or CRT. If the appropriate corrective action measures are unsuccessful and the Orbiter must return and land, an abort dump of both Tug propellants is required. Three modes of accomplishing Tug propellant dump are available. In the primary mode an automatic sequence is executed by the Tug DMS upon command from the commander or mission specialist. Two backup modes ensure abort operations through an MSS automatic sequence and, if necessary, the MSS operator can execute the abort controls manually.

Three abort control switches, shown in Figure 3-8, allow control of abort enable, manual versus automatic operation, and abort execution command. If the manual abort mode is selected, seven additional switches allow control of the individual abort operations to allow the dumping of Tug LH_2 and LO_2 propellants. Dump of Tug propellants requires application of suitable settling thrust to orient the propellants over the tank drain outlets. Orbiter thrust availability is dependent on the mission phase during which abort is initiated, as identified in Figure 3-9.

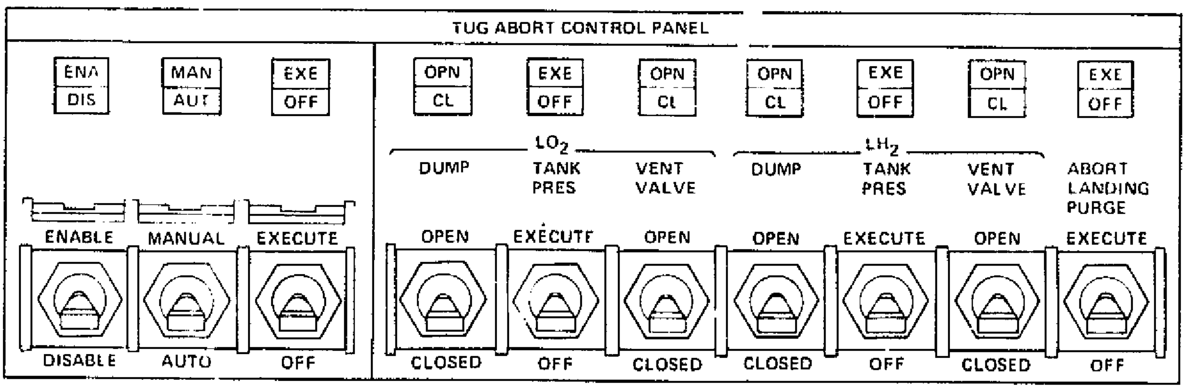
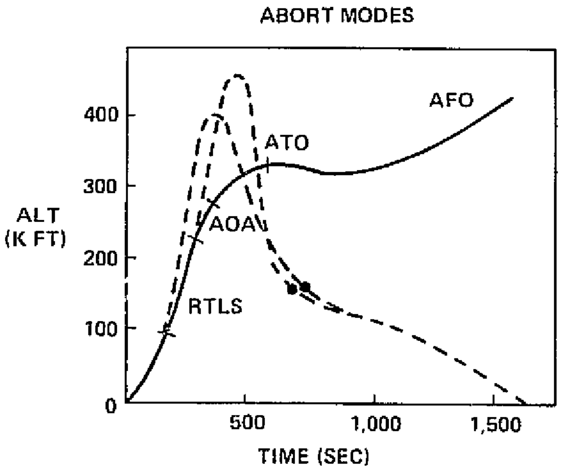


Figure 3-8. Tug Abort Control Panel



PROPELLANT DUMP

MODE	SETTLING THRUST & TIME (SEC)		
	INITIAL	INTERMEDIATE	TERMINAL
RTLS		SSME 300	
AOA	SSME	SSME/OMS	OMS
ATO	OMS 20	DUMP 1030	(4)RCS 50
AFO	OMS/RCS 20	DUMP 1030	(4)RCS 50

Figure 3-9. Propellant Dump Settling Requirements

For early aborts, return to launch site (RTLS), and initial portions of abort once around (AOA), sufficient settling thrust and duration are provided by the Space Shuttle main engines (SSME) or orbital maneuvering system (OMS) for dump completion. For later aborts, abort to orbit (ATO) or abort from orbit (AFO), the Orbiter has insufficient propellant quantity and settling thrust to provide orientation from dump initiation to propellant depletion. To obtain complete dump during these abort modes, Tug propellants are exhausted axially at the Orbiter dump ports to provide settling thrust during the intermediate dump period. Orbiter OMS or RCS thrust is used at dump initiation and termination for settling orientation and residual reduction respectively.

3.4 PREDEPLOYMENT THROUGH ROTATION

Once the Orbiter has reached circular earth orbit, Tug/Spacecraft status display, deployment, and initialization operations occur. These activities are primarily under Orbiter crew control, with ground capability available as a backup.

The Tug unique aft crew cabin control and monitor functions fall into two main categories: 1) those associated with Tug initialization, checkout, and safing operations, and 2) those associated with deployment and capture of the Tug and its spacecraft from the Orbiter.

Tug deployment/capture functions are located near the aft window at the payload handler station and the initialization, C/O, and safing panel is located near the MSS CRT display. In general, the switch functions shown in Figure 3-10 are arranged so that their operation proceeds from left to right and the indicated function is executed when the switch is in the up position. Two status lights are shown above each function switch to indicate function status (function initiated - Red; function complete - Green). Operation of a switch function will alert the Orbiter data processor supporting Tug operations and execute Tug-unique software to control and monitor automatically the events necessary to perform the desired operation. Operation flow status and anomalous conditions will be displayed to the operator through messages on the MSS CRT.

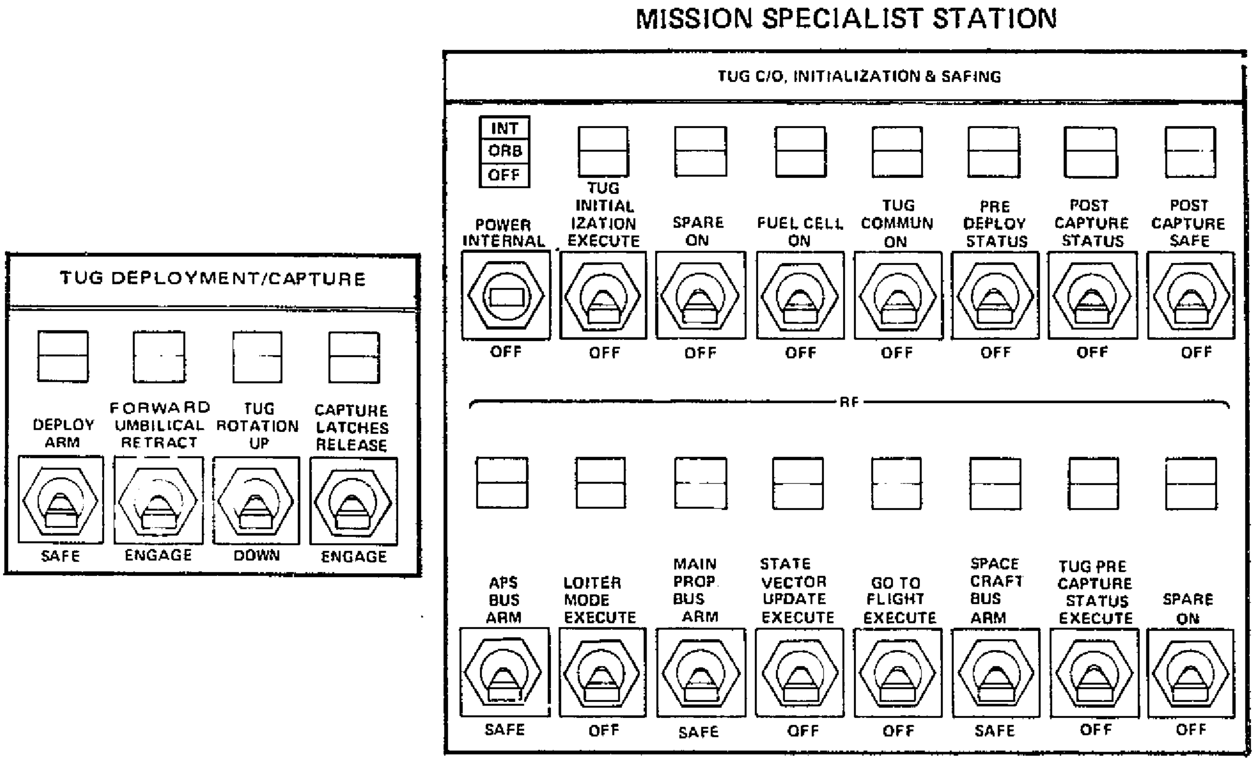


Figure 3-10. Tug Crew Compartment Deployment Displays

The deployment sequence illustrated in Figure 3-11 is initiated by performing status verification. Arming of the deployment adapter arm/safe switch allows power application for deployment functions, the forward umbilical panel is retracted, the Orbiter releases the forward support fitting latches, and D/A actuators rotate the Tug to its 35-degree removal position, which disengages the aft fluid umbilicals. The communication handoff from through-adapter hardwire to direct Tug/Orbiter RF is accomplished and verified at this time. RMS attachment to the Tug end effector socket is

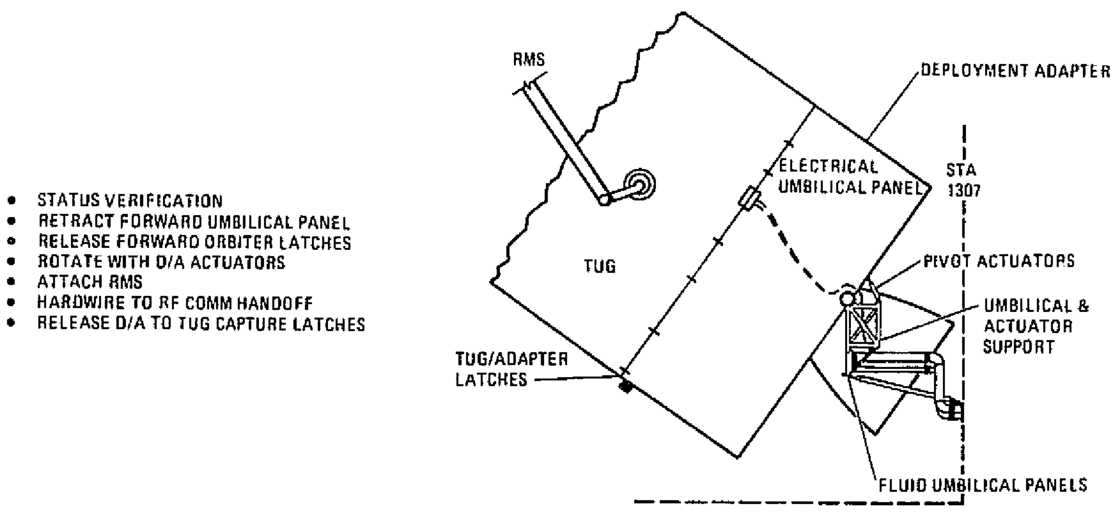


Figure 3-11. Tug Deployment Sequence

followed by release of the D/A capture latches. Latch release includes a push-apart motion, which disengages Tug-to-D/A alignment devices and electrical umbilicals.

3.5 TUG REMOVAL WITH RMS

When the Tug and deployment adapter are disengaged by the capture latches, the Orbiter remote manipulation system (RMS) assumes full responsibility for Tug position and attitude control. Initial RMS/Tug engagement is performed with the Tug in the 35-degree (0.2 π rad) rotated position. An Orbiter crew-initiated preloaded computer program positions the RMS so that its end effector is aligned but approximately 3 ft (1 m) away from the Tug socket. The RMS wrist-mounted TV camera gives visual verification of proper alignment. If a lateral or rotational position error exists, a manual adjustment control is used for nulling. The computer program is continued, with manual jog override, until RMS attachment is accomplished. Tug removal from the deployment adapter is simiarly performed. A preloaded computer program with manual adjustment control capability is used, with a D/A-located TV camera used for crew visual monitoring. Once the Tug clears the adapter, positioning continues through computer control with direct visual progress assessment by Orbiter crew members. Tug deployment RMS requirements for processor control with manned supervisory override are summarized in Figure 3-12.

OPERATION	VIEWING PROCEDURE	CONTROL REQUIREMENT
RMS ATTACHMENT	FWD BHD WINDOW	COMPUTER PLACEMENT PLUS MANUAL JOG
	TV ON RMS WRIST	MANUAL JOG
REMOVAL	FWD BHD WINDOW	COMPUTER PATH CONTROL
	TV ON D/A	MANUAL JOG
PLACEMENT	CREW COMP CEILING WINDOW	COMPUTER PLACEMENT
GENERAL RMS USE	CREW COMP WINDOWS	COMPUTER ENVELOPE RESTRICTION

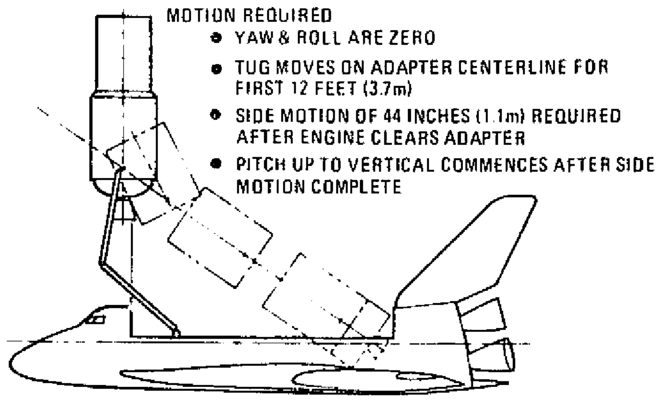


Figure 3-12. RMS Procedure for Tug Deployment

3.6 ORBITER VICINITY

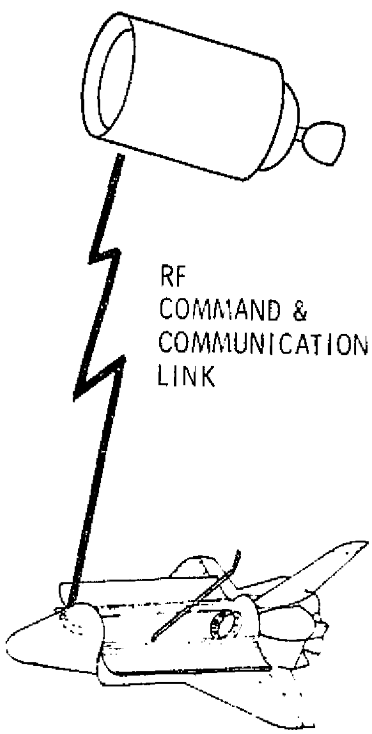
Following the Orbiter hardwire-to-RF communications handoff, Tug status verification, and RMS release, the Orbiter immediately performs a backup maneuver with its nose-mounted axial RCS thrusters. An Orbiter separation velocity of 5.5 ft/sec (1.7

m/sec) provides a 1-mile (1.85 km) separation in 16 minutes and meets spacecraft thruster impingement contamination constraints. After an initial Orbiter to Tug clearance is obtained (suggest 100 ft (30 m)), the Tug APS is armed to enable Tug attitude stabilization. When the 1-mile (1.85 km) separation is achieved, Tug control is transferred from Orbiter to ground. During the 1-mile (1.85 km) initial separation, and following ground handoff, the Orbiter has primary and backup control, respectively, of Tug APS and main propulsion systems through arm/safe switches located in the crew compartment. This backup capability should be limited to a Tug vicinity of 20 miles (37 km). The extension of the Tug main engine nozzle is performed under ground control.

Tug retrieval operations before Ground/Orbiter control handoff encompass the dr and vent of main propellant tanks, retraction of the main engine nozzle, main propulsion system safing, attitude holding through the APS, and status (safe for Orbiter retrieval) verification. After handoff has been accomplished, the Orbiter crew verifies the Tug safety status and performs the rendezvous maneuver. The Orbiter approaches the Tug and positions its RMS within wrist extension distance (24 in. (61 cm)) of the Tug end effector socket. When this alignment is obtained, both the Tug and Orbiter auxiliary propulsions systems are turned off (Tug's via Orbiter controlled arm/safe switch), RMS is attached to Tug, and the Orbiter RCS is reenabled to maintain Orbiter attitude. These deployment and retrieval functions, summarized in Figure 3-13, are all accomplished through the Orbiter RF communication link.

DEPLOYMENT

- STATUS VERIFICATION
- RMS RELEASE
- ORBITER BACKUP MANUEVER
- TUG APS ARM
- GROUND CONTROL HANDOFF
- MAIN PROPULSION ARM (ORBITER B/U)
- EXTEND MAIN ENGINE NOZZLE



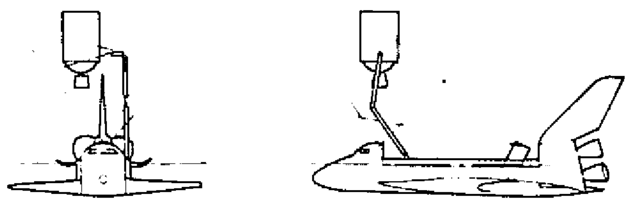
RETRIEVAL

- TUG PROPELLANT DUMPED/VENTED
- ATTITUDE HOLD
- RETRACT MAIN ENGINE NOZZLE
- TUG PROPULSION SAFE (ORBITER B/U)
- STATUS VERIFICATION
- ORBITER CONTROL HANDOFF
- STATUS VERIFICATION
- ORBITER APPROACH
- RMS POSITIONING
- TUG APS SAFE
- ORBITER RCS OFF
- RMS ATTACHMENT

Figure 3-13. Tug Operations in Orbiter Vicinity

3.7 TUG CAPTURE

RMS alignment. attachment, Tug positioning, and deployment adapter insertion are performed using a computer-controlled man-in-the-loop operation with direct and TV augmented monitoring. Each major segment of the operation has specific viewing procedures and control requirements associated with it, as indicated in Figure 3-14. TV cameras mounted on the RMS wrist and deployment adapter structural shell provide the additional operator monitoring needed to oversee and adjust the preprogrammed insertion sequence.



OPERATION	VIEWING PROCEDURE	CONTROL REQUIREMENT
RMS ALIGNMENT	CREW COMP CEILING WINDOW PLUS TV ON D/A PLUS TV CN RMS WRIST	COMPUTER PLACEMENT PLUS MANUAL VELOCITY & JOG ADJUSTMENTS
RMS ATTACHMENT	ALL OF ABOVE	MANUAL WRIST EXTENSION PLUS GRASP SWITCH ON END EFFECTOR
ALIGN TUG WITH D/A	FWD BHD WINDOW PLUS TV ON D/A	COMPUTER PLACEMENT PLUS MANUAL JOG
D/A INSERTION	SAME AS ABOVE	SAME AS ABOVE

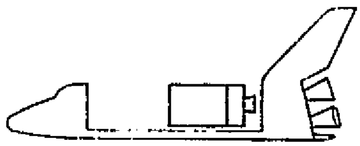
Figure 3-14. RMS Procedure for Tug Retrieval

3.8 POSTRETRIEVAL OPERATIONS

After Tug deployment adapter insertion has been completed, three Tug/Orbiter operational periods occur before mission completion, as shown in Figure 3-15.

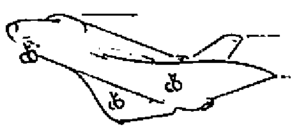
RMS Tug/deployment adapter insertion is accomplished with the adapter held in its 35-degree (0.2 π rad) rotated position by the D/A rotation actuators. Fine positioning alignment of Tug and D/A is provided by adapter-mounted indexing devices, which engage Tug umbilical panel support struts. Insertion is completed by D/A capture

CARGO BAY INSTALLATION



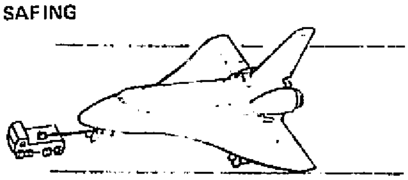
- ENGAGE D/A TO TUG CAPTURE LATCHES
- VERIFY HARDWIRE COMM CAPABILITY
- RF TO HARDWIRE HANDOFF
- ROTATE TUG INTO CARGO BAY
- ENGAGE FWD LATCHES
- ENGAGE FWD UMBILICAL PANEL
- SWITCH TO ORBITER POWER
- SHUT DOWN TUG FUEL CELLS
- PURGE & REPRESSURIZE
- D/A SAFE

LANDING



- MAINTAIN PROPELLANT TANK PRESSURE
- MONITOR CAUTION & WARNING FUNCTIONS

SAFING



- HOOK UP GRND H_2 VENT LINE TO T-0 PANEL
- TRANSFER FROM IN FLIGHT TO T-0 PANEL H_2 VENT
- ADDITIONAL PURGING
- TUG REMOVAL (GRND POWER UMBILICAL)

Figure 3-15. Postretrieval Operations

latch engagement, which draws the separation interface together and mates the safety critical (caution and warning) electrical umbilicals. RF to hardwire communications handoff is verified, and the Tug plus deployment adapter is rotated 35 degrees (0.2 π rad) back into the cargo bay, followed by forward support fitting latch engagement and Orbiter verification. The forward Orbiter to Tug umbilical panel for payload use is re-engaged, power supply transferred from Tug to Orbiter fuel cells, and the Tug fuel cells are shut down. Tug propellant tank safing and repressurization is accomplished by using the abort helium supply located in the deployment adapter. The deployment adapter system (capture latches, rotary actuators) is safed for return by removing the power supply to these functions.

Landing operations are primarily involved with maintaining Tug propellant tank and tank MLI systems pressures above ambient and monitoring the applicable Tug caution and warning functions.

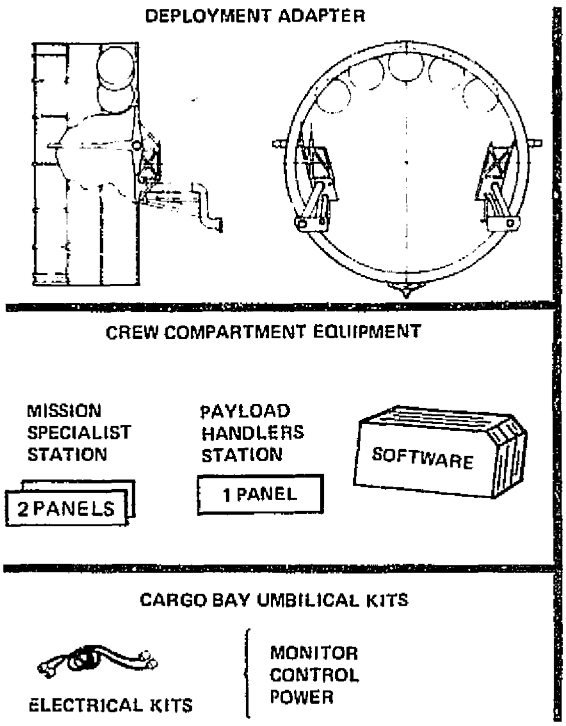
No special operations are associated with Orbiter touchdown. After rollout, additional Tug propellant tank and insulation purging is accomplished using ground-supplied helium. Post-landing hydrogen venting, if required, is performed with the Orbiter in-flight relief until an appropriate GH_2 vent umbilical is attached to the Orbiter T-0 fuel panel disconnect. Safety monitoring capability during Tug removal is supplied through a deployment-adapter-attached ground power umbilical.

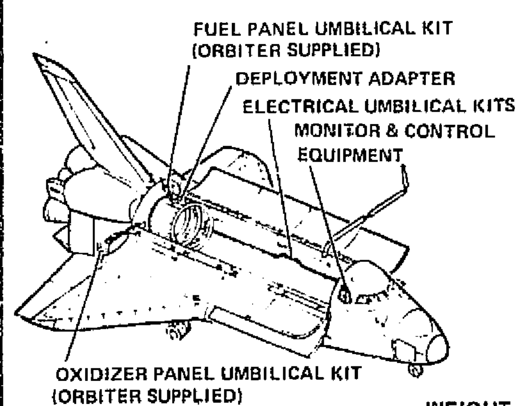
SECTION 4

INTERFACE DEFINITION — PHYSICAL DESCRIPTION

Based on the deployment adapter (D/A) system selection for Tug/Orbiter interfacing presented in Section 2.4, detailed description of the Tug-peculiar peripheral equipment was accomplished. In addition to the cylindrical D/A structure, peripheral equipment includes monitor and control panels and software, mechanisms, umbilical panels, and fluid electrical umbilical kits.

Tug peripherial equipment can generally be separated into the three categories shown in Figure 4-1: payload bay support equipment (deployment adapter), crew compartment equipment, and umbilical kits that connect Tug plus deployment adapter to ground umbilicals and Orbiter crew controls.





EQUIPMENT	WEIGHT (POUNDS)	(KG)
ADAPTER STRUCTURE & MECHANISMS	692	314
UMBILICAL SUPPORT & MECHANISMS	98	44
FLUID SYSTEM	737	335
AVIONICS HARDWARE	273	124
INTEGRATION ASSY & C/O	0	
AVIONICS SOFTWARE	0	
TOTAL	1,800	817

Figure 4-1. Tug/Orbiter Peripheral Equipment Description

Deployment Adapter. The adapter consists of a load-carrying cylinder that provides deployment positioning and contains subsystem interface equipment, including the abort helium storage bottles, umbilical panels, and interface electronics.

Crew Compartment Equipment. The Tug uses Orbiter-supplied man-machine interface monitor and control equipment located in the crew compartment, data processor, memory storage, and the pilot and commander's CWA panels. The Tug-supplied equipment needed to use this Orbiter-supplied equipment includes two display/control panels for the MSS and one for the payload handler station, plus integration software.

Cargo Umbilical Kits. Tug fluid kits are included in the deployment adapter. The only separate kits are those for monitor and control electrical wiring, Tug power, and the forward umbilical panel disconnect mechanisms and lines.

To fully understand the detail Tug interface requirements, the Tug configuration and Orbiter interface equipment used by Tug must be defined. The MSFC baseline Tug preliminary design needed additional definition in several areas, specifically fluids and avionics, to permit deployment of detail interface requirements. This expanded Tug definition is included in Section 4.1. Additional details of recommended Tug changes are included in Section 6 of this volume.

Orbiter interfaces are as described in the Space Shuttle Shuttle System Payload Accommodations document JSC 07700 Vol. XIV, Rev. C, with additional definition/clarification of Tug-related interfaces as requested by the Interface Study with proposed changes. Details of these requested accommodations revisions are contained in Section 5 of this volume.

Following the Tug configuration description, subsections contain detailed interface requirements for deployment adapter (4.2), crew compartment equipment (4.3), and cargo bay umbilical kits (4.4).

4.1 TUG CONFIGURATION DESCRIPTION

This Section contains detailed Tug information developed by General Dynamics Convair to aid in obtaining Tug/Orbiter interface requirements. Included are the recommended Tug configuration inboard profile, fluid system schematic, and Tug avionics system.

4.1.1 TUG INBOARD PROFILE. Figure 4-2 describes the recommended Tug configuration developed during the Interface Study to define detail Tug-to-Orbiter interface requirements. The design concept shown is based on the MSFC baseline Tug as described in MSFC 68M00039-2. The overall dimensions, tankage arrangement, and many systems descriptions have remained unchanged. Some revisions were needed, however, for Tug compatibility with recommended interface implementation details obtained by study analyses. A comprehensive discussion of these recommended changes is contained in Section 6.

Tug and deployment adapter (D/A) are shown in their mated position as installed in the Orbiter cargo bay (Figure 4-2). The separation plane between Tug/deployment adapter is Orbiter station X_o 1172.9. The Tug's aft LO_2 tank bulkhead, fluid umbilical panels,

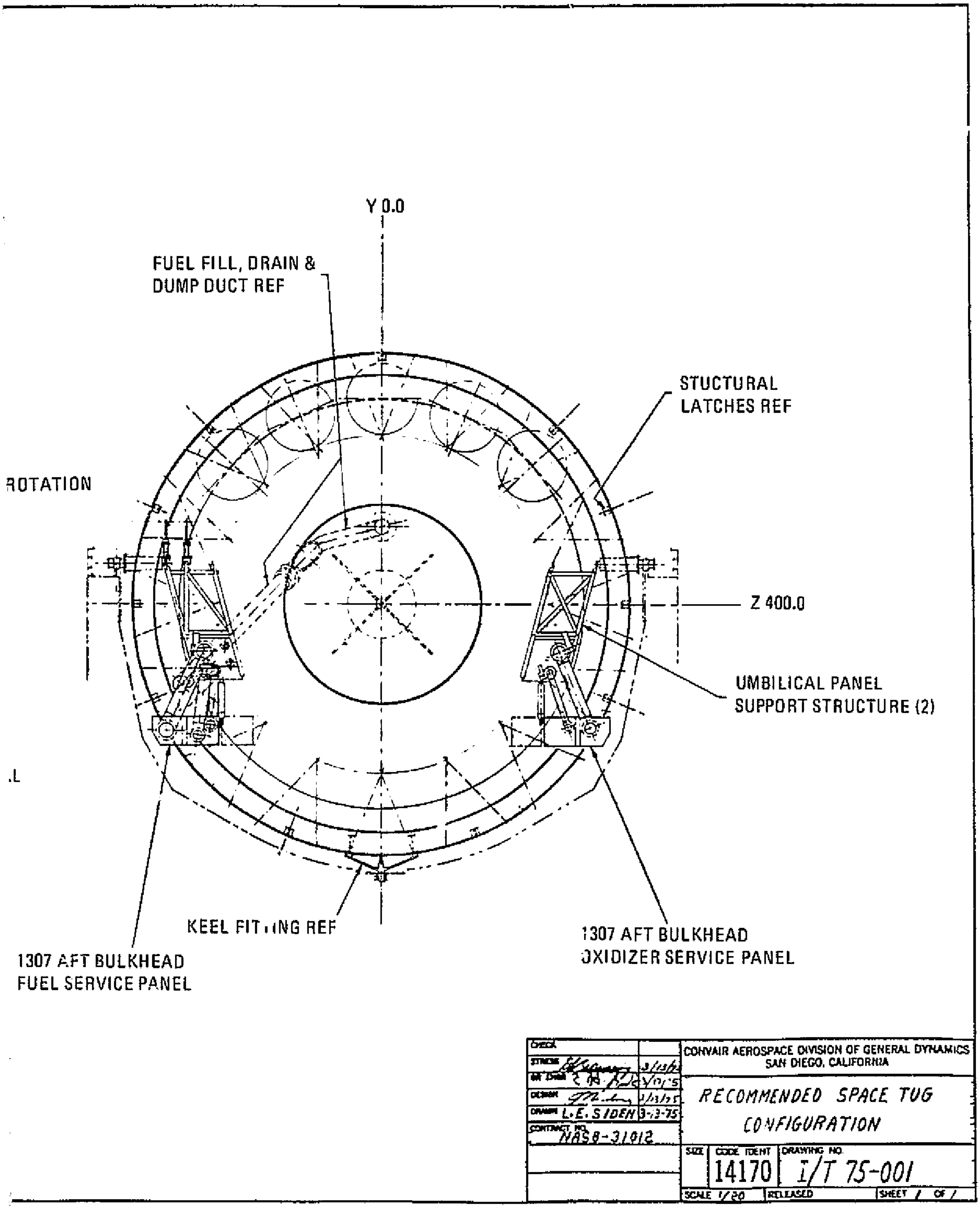


Figure 4-2. Recommended Space Tug Configuration (Drawing I/T 75-001)

and main engine are enveloped by the D/A cylindrical structural shell. All the major physical interfaces between Tug plus D/A and Orbiter are shown:

a. Six structural support fittings.

b. Two aft umbilical panel stabilizing struts.

c. The Station 1307 fluid service panel connections.

d. The forward umbilical panel connection (for Tug payload services).

The only physical interface not shown is the aft electrical umbilical containing Tug/payload data link communications and safety hardwires. The cable is routed from the Tug/deployment adapter disconnect interface (at X 1172.9), through the D/A, past the X_o 1246 X/Z pivot, to a connector at the Station 1307 electrical service panel. This routing does not go through the aft Tug fluid umbilicals.

Tug details of particular interest to deployment adapter are: location of fluid umbilical panels, and the corresponding routing of propellant fill, drain, dump, topping and vent/relief lines. The position of the Tug RMS end effector socket is also noted.

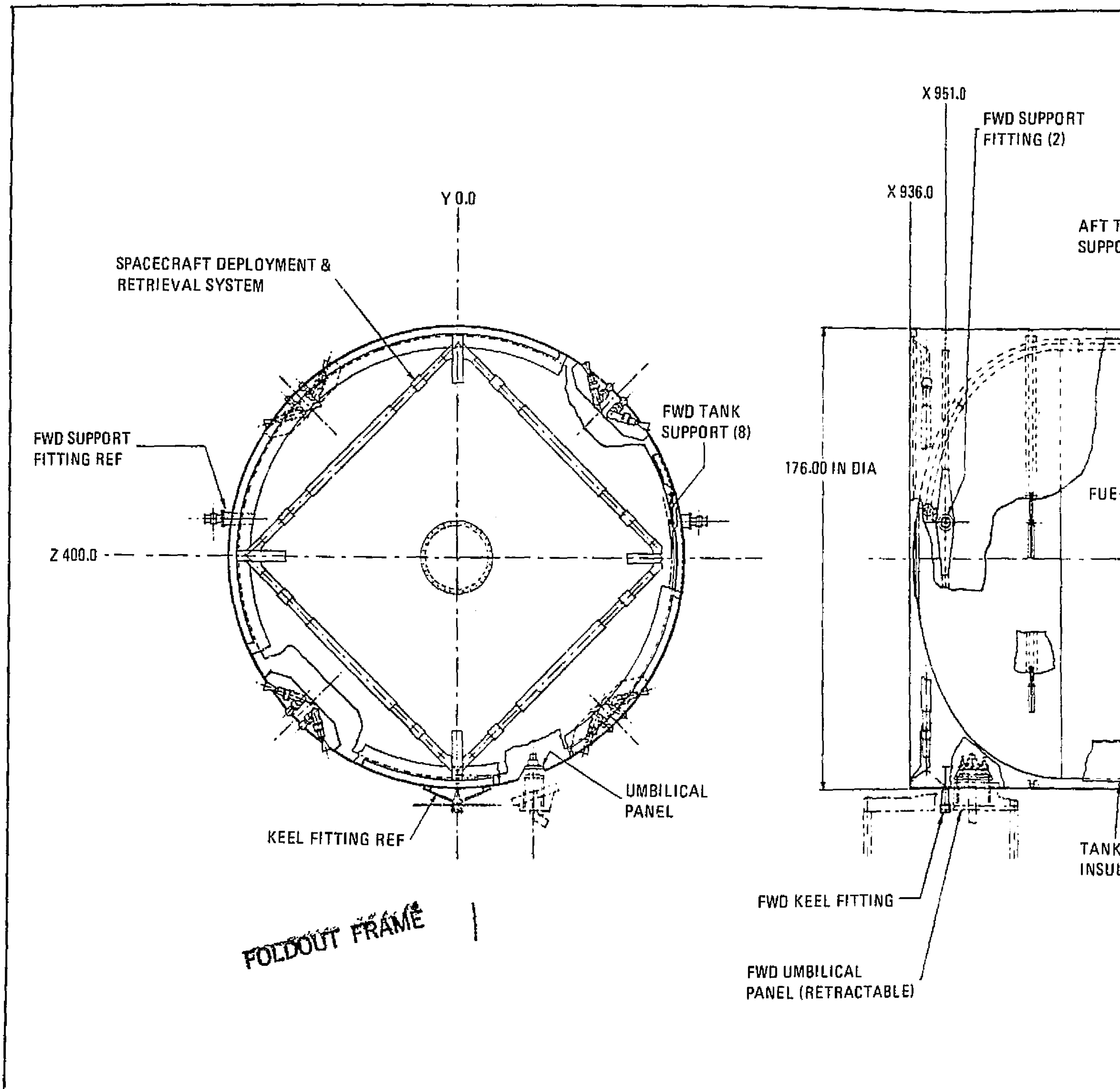
4.1.2 FLUID SYSTEM SCHEMATIC. Figure 4-3 shows the Tug, D/A, and Orbiter interface fluid schematic. It includes the Tug main propulsion, pressurization, fill/drain/vent, auxillary propulsion, and fuel cell fluid systems. It also shows the D/A abort/safing pressurization system and umbilical panels.

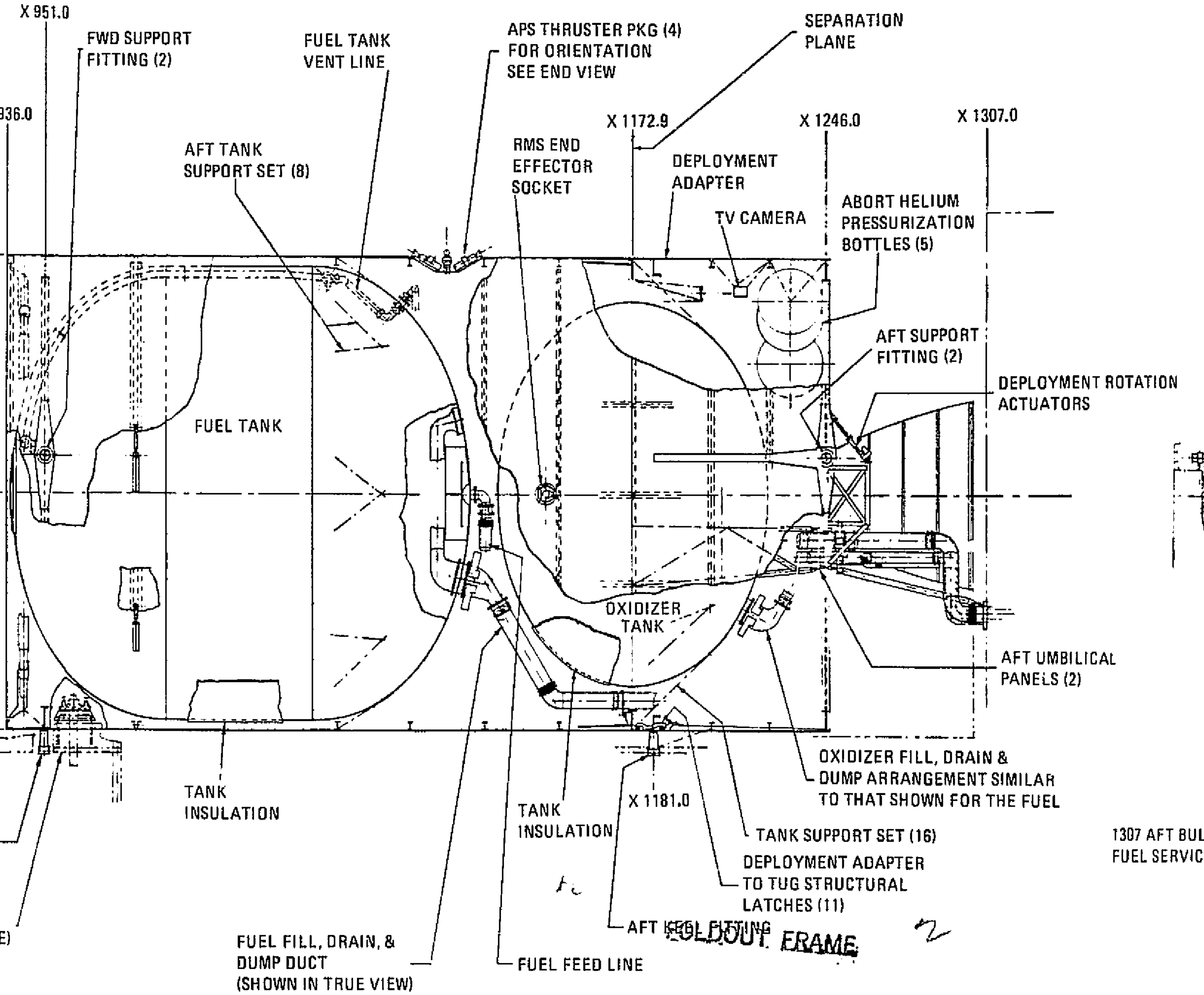
This fluid system schematic is the updated version of that shown in Figure 4.6-6 of Volume II. In Volume II, Figure 4.6-6 was used for fluid system analyses in Section 4.4, avionics power requirements development in Section 4.6, and interface safety analyses in Section 4.7. Revision C to this schematic, shown in Figure 4-3, incorporates all the revisions that resulted from these subsystem investigations.

The following fluid schematic details with respect to the MSFC baseline Tug are of particular interest:

a. The auxiliary propulsion system (APS) reflects a dedicated helium supply and a revised helium and N_2H_4 relief system. For Orbiter attached and near proximity modes, helium valve 010 and N_2H_4 valve 057 would remain open to assure over-pressurization protection. During Tug mission phases away from the Orbiter, these two valves are closed to provide increased APS propulsion system reliability.

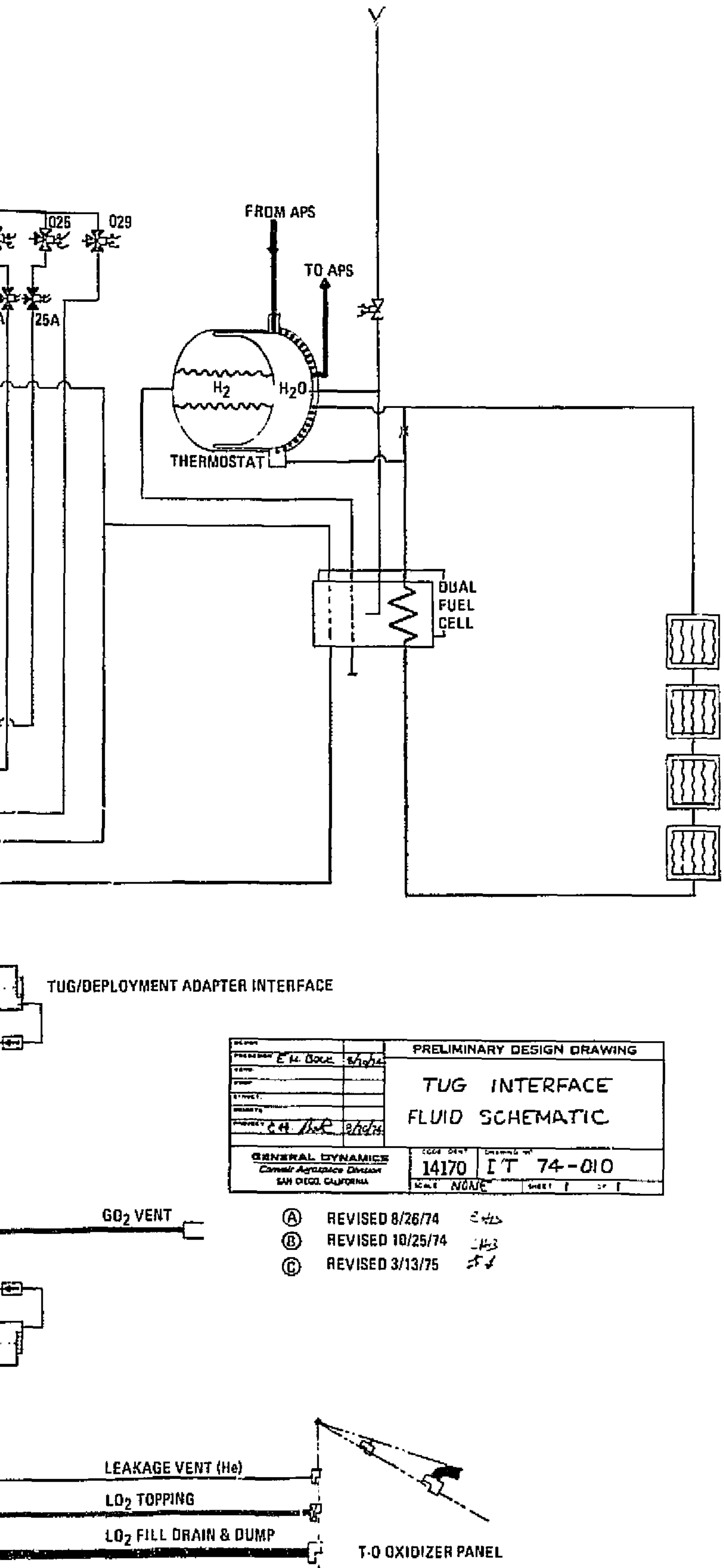
b. The hydrogen propellant fill, drain, dump, and vent ducting has been revised to reflect RTLS LH_2 dump capability. Separate engine feed and fill/dump lines, similar to the LO_2 tank, are now shown. The horizontal drain capability has been deleted for the hydrogen tank. The oxygen tank plumbing remains unchanged except for the addition of a LO_2 topping line.


Y 0.0
SPACECRAFT DEPLOYMENT &
RETRIEVAL SYSTEM
FWD SUPPORT
FITTING REF
FWD TANK
SUPPORT (8)
Z 400.0
UMBILICAL
PANEL
KEEL FITTING REF
X 951.0
FWD SUPPORT
FITTING (2)
X 936.0
176.00 IN DIA
FWD KEEL FITTING
FWD UMBILICAL
PANEL (RETRACTABLE)
FOLDOUT FRAME



FOLDOUT FRAME 2

Figure



Schematic (Drawing I/T 74-010 Revision C)

c. The fuel cell system has been changed from modified Orbiter to a new-technology, thermally integrated, lightweight system. This change, proposed by the Tug Avionics Definition Study, deletes the separate dedicated LH_2 and LO_2 storage bottles and four Tug/Orbiter interface umbilicals: fuel cell LO_2 F&D, fuel cell LH_2 F&D, ground coolant in, and ground coolant out. Fuel cell startup for prelaunch checkout and operation during ascent is made thermally feasible by employing onboard H_2O and N_2H_4 heat exchangers. Radiators are used for on-orbit cooling, as for the modified Orbiter fuel cell.

d. The schematic has been expanded to include the deployment adapter and Orbiter portions of the Tug fluid system. The deployment adapter incorporates the abort dump helium pressurization system, umbilical panel purge system, and the helium control solenoids for the D/A mounted hydrogen vent selector valves. In addition to the remote hydrogen vent, two other Tug interfaces are not included in the Orbiter T-0 launch umbilicals:

   GO_2 Vent — This is located in the Orbiter skin line just forward of the Station 1307 bulkhead. It therefore has no 1307 panel interface.

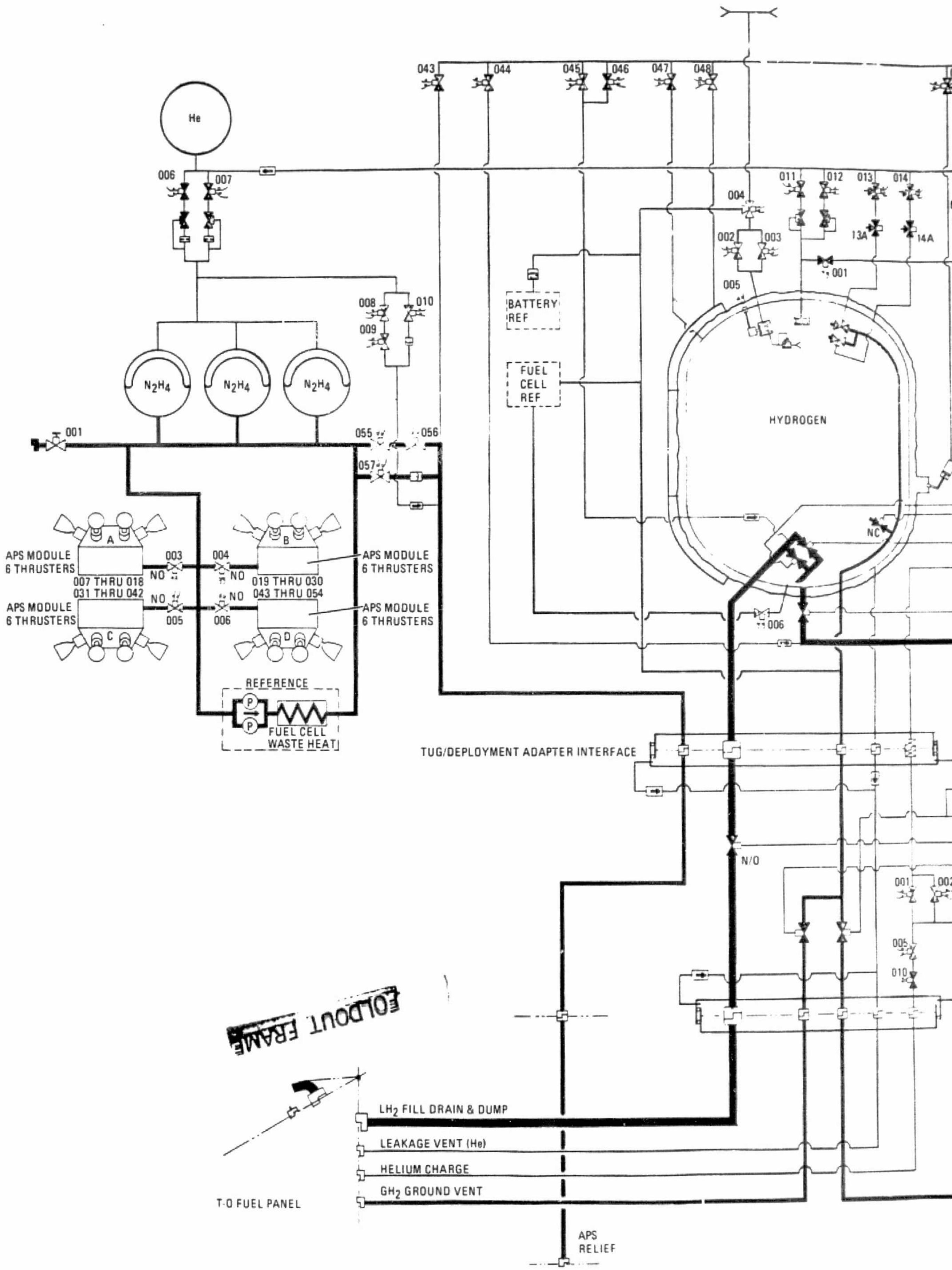
   N_2H_4 Relief — This line uses the plumbing raceway provided for storable IUS stages. Its exit is located in the Orbiter 535 panel on the thrust structure fire wall just beneath the port OMS pod. If Orbiter storable service kits are not supplied on Tug missions (by Orbiter) the N_2H_4 relief will be added to the Tug 1307 fuel panel.

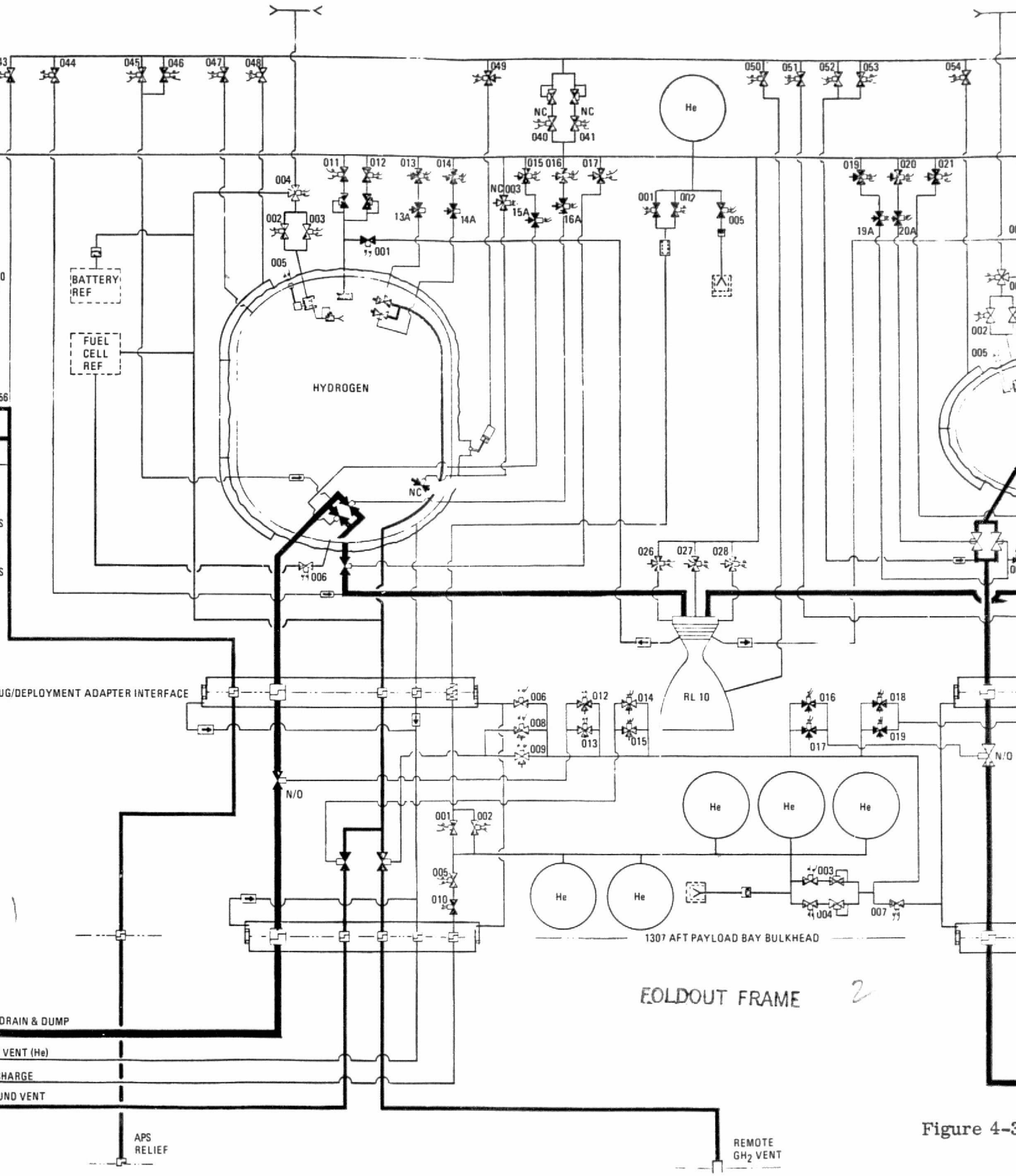
Disconnect halves and/or flow deflectors are shown on the T-0 umbilical panel doors for four Tug umbilicals. The LH_2 and LO_2 dump lines must have axial dump capability during on-orbit aborts to provide propellant settling thrust. The propellant tank insulation purge vents must have continual vent capability during Orbiter ascent.

4.1.3 TUG AVIONICS DESCRIPTION. The description of Tug avionics supplied in this section was obtained from the Space Tug Avionics Definition Study, final report number CASD-NAS75-012, performed for MSFC by GDC under Contract NAS8-31010. This information was used in developing final avionics interface recommendations for the Interface Compatibility Study.

Tug avionics hardware is installed on the vehicle in both forward and intertank locations as shown in Figure 4-4. Integration of the thermal control subsystem as well as access flexibility in the maintenance/refurbishment task is consistent with the equipment layout.

The forward equipment area provides for canted shelf, right-angle shelf, and shell-mounted units. Each of the four quadrants displays a certain functional dedication. Each quadrant contains an interfacing DIU (or CIU) and provides for mechanical isolation and/or easy implementation of a common mechanical reference as is required within the GN&C and R&D subsystems. Shell-mounted devices are primarily antennas.


He
006
007
008
009
010
N_2H_4
N_2H_4
N_2H_4
001
055
056
057
APS MODULE
6 THRUSTERS
A
B
C
D
003
004
005
006
NO
007 THRU 018
031 THRU 042
019 THRU 030
043 THRU 054
APS MODULE
6 THRUSTERS
APS MODULE
6 THRUSTERS
APS MODULE
6 THRUSTERS
REFERENCE
FUEL CELL
WASTE HEAT
043
044
045
046
047
048
BATTERY
REF
FUEL
CELL
REF
HYDROGEN
011
012
013
014
13A
14A
004
002
003
001
005
NC
006
TUG/DEPLOYMENT ADAPTER INTERFACE
N/O
001
002
005
010
LH_2 FILL DRAIN & DUMP
LEAKAGE VENT (He)
HELIUM CHARGE
GH_2 GROUND VENT
T-0 FUEL PANEL
APS
RELIEF



FOLDOUT FRAME 2

Figure 4-3

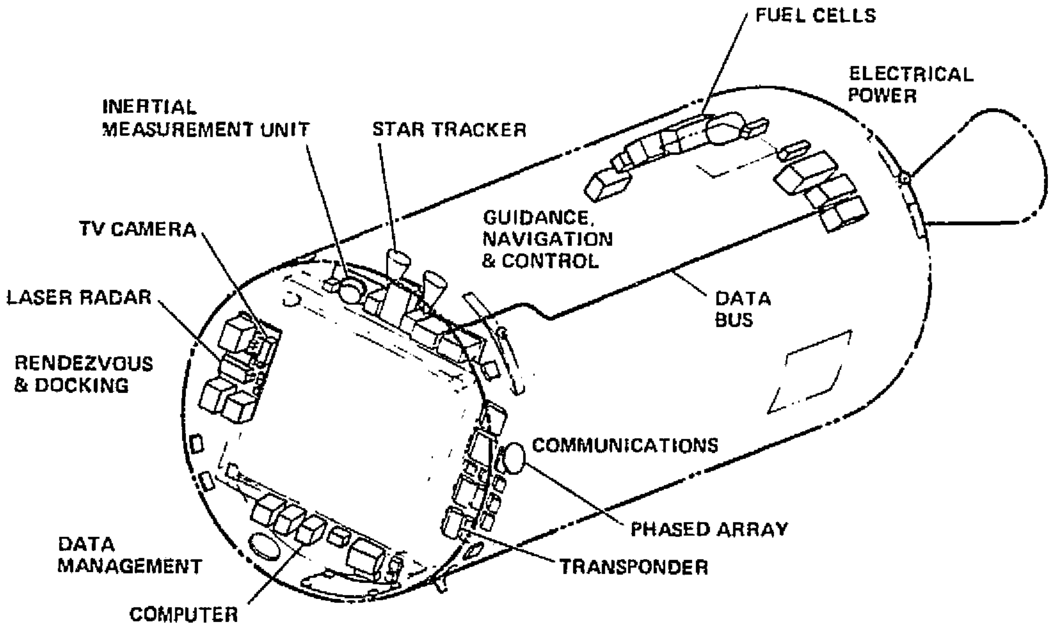


Figure 4-4. Tug Avionics Hardware

The intertank equipment area accommodates either right-angle shelf or shell-mounted units. Shell-mounted devices are limited to the four EPS fuel cell radiators. The power distribution unit (aft PDU) in the intertank area interfaces with the deployment adapter for external power and safety functions. A single interfacing DIU and the engine control unit service the Tug thrust section (and deployment adapter as required for safety) from their intertank locations.

Hardware identified in Figure 4-4 includes some changes to initial MSFC baseline Tug avionics.

The equipment list shown in Table 4-1 is the latest list as evolved from the outputs of the Avionics Definition Study for Space Tug.

The configuration established for the Space Tug avionics system is shown in the block diagram of Figure 4-5. This system is structured around a digital, centralized data management computer that controls the avionics components via a redundant digital data bus and through digital interface units (DIU). Bus traffic to and from the DIUs is controlled by the computer interface units (CIU). In the diagram the components are grouped by subsystem, for convenience.

Directly below the CIUs are the communication subsystem components, highlighted by the three cross-hatched circles representing the electronically steerable phased arrays.

Table 4-1. Tug Avionics Equipment List

EQUIPMENT	NO. REQ	ENVELOPE DIMENSIONS			UNIT WEIGHT	UNIT POWER (WATT)	SUB SYSTEM WEIGHT (LB)	(KG)
DATA MANAGEMENT							100	45.4
DIGITAL COMPUTER	(1)	10	14	9.5	34	60		
CIU	(2)	5	5	6.5	6.5	7		
DIU	(8)	5	5	6.5	5	5		
TAPE RECORDER	(1)	10	8	5	13	20		
GUIDANCE, NAVIGATION & CONTROL							190	86.2
INERTIAL MEAS UNIT	(1)	9 x 9 DIA			25	100		
IMU ELECTRONICS	(1)	10	20	5	30	100		
RATE GYROS	(1)	10	10	6	20	100		
STAR TRACKER	(2)	6	8	12	16	12		
SUN SENSOR	(2)	6.9	6.5	3	4.5	5		
CONTROL ELECTRONICS	(1)	12	12	18	50	50		
ILT-ANTS./RECEIVER	(1)	12	10	9	24	15		
RENDEZVOUS & DOCKING							63	28.6
SCANNING LADAR	(1)	6	8	20	28	10		
& ELECTRONICS	(1)	9	9	11	11	30		
TV CAMERA & ELECTRONICS	(2)	6	6	15	8	10		
TV STROBE LAMPS	(4)	3.5	3.5	3.5	1			
STROBE ELECTRONICS	(2)	2	3.5	2.5	2			
COMMUNICATIONS							149	67.6
ELEC STEERED PHASED ARRAY	(3)	3.5 x 15 IN. DIAM			16	93		
OMNI ANT/NETWORK/SWITCH	(1)	5	5	6	11.3	3		
TRANSPONDER	(2)	15	7	6	16.5	16		
SIGNAL PROCESSOR	(2)	13.5	6	6.5	11	18		
COMMAND DISTRIB	(1)	5	5	4	18	35		
SGLS ENCRYPTER	(2)	6	4	5	4.3	7		
SGLS DECRYPTER	(2)	6	4	5	4	2.5		
INSTRUMENTATION							74	33.6
TRANSDUCERS	(243)				20	--		
SIGNAL CONDITIONERS	(3)	12	10	6	18	22		
ELECTRICAL POWER, DIST & CONTR							322	
FUEL CELLS POWERPLANT	(2)	12	6	15	42	20		
EMERGENCY BATTERY (150 AH)	(1)	8	11	7	36	–		
PWR DISTRIBUTION					46	–		
PWR PROCESSING	(2)	9	9	8	8	–		
HARNESSES/SWITCHES/MISC					140			
AVIONICS SYSTEM WEIGHT 898 LB (407 KG)								

To the right are the TV and scanning laser radar (LADAR) associated with the rendezvous and docking subsystem, and then the guidance and navigation subsystem components distinguished by the dodecahedron inertial measuring unit (IMU) and the four spiral antennas of the interferometric landmark track[illegible] (ILT). Below these two subsystems are the components physically located in the aft part of the Tug between the main propellant tanks. The fuel and power pl[illegible]re located there as well as the flight control electronics and the commands and con[illegible] to the nonavionics systems.

At the bottom of the diagram is the interface to the Orbiter and ground; at the top of the diagram is the interface with the Tug's spacecraft.

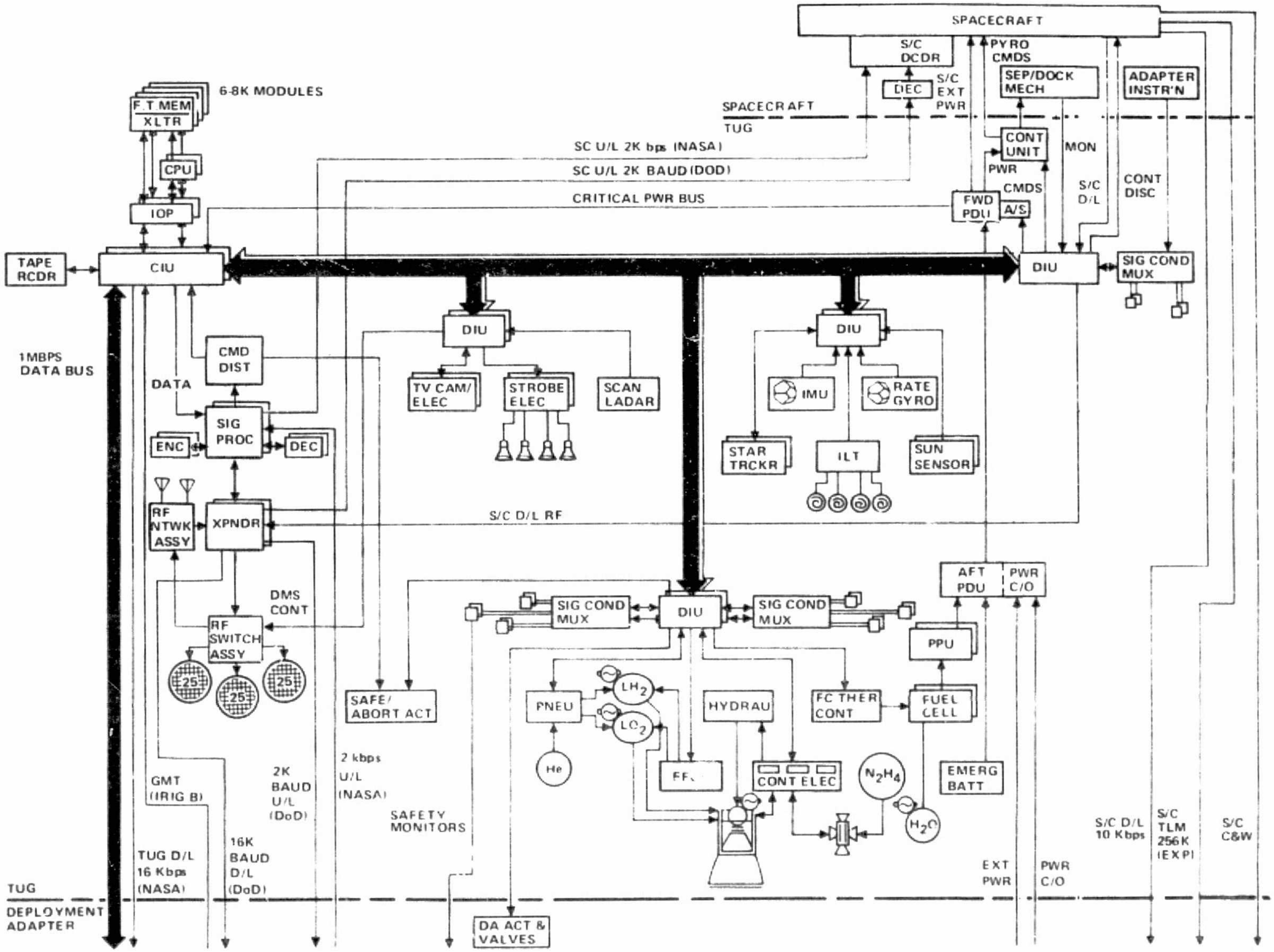


Figure 4-5. Tug Avionics System Block Diagram

Tug interfaces shown in Figure 4-6 are responsive to spacecraft support requirements, Orbiter safety requirements, Orbiter capability, and Tug support requirements of the Orbiter. Power is provided to the spacecraft from either the Tug power system, Orbiter power, or ground power (Tug external power) through the Tug.

The Orbiter hardwire interface with the Tug includes a 2 kbps uplink. The 2 kbps uplink is shared between Tug and the spacecraft with each doing their own decoding. (These links are established by Tug RF when detached from the Orbiter.) A 1 mbps bidirectional bus is used on the ground both prior to and after electrical mating with the Orbiter. This bus provides a high response path for software loading, updates, and safety reaction subroutines.

Downlinks are accommodated by a 10 kbps spacecraft link and a 16 kbps Tug telemetry link. The spacecraft downlink is both hardwired through Tug and passed through a Tug DIU where data may be stripped out by the DMS if necessary to support spacecraft requirements. The DIU interfacing downlink data is also interleaved with Tug data during detached operations. A separate link for spacecraft experiment data is provided straight through Tug to the Orbiter along with spacecraft safety hardwires.

A separate downlink and uplink are provided for DOD for two reasons:

a. Orbiter equipment is different: uplink and downlink wires come from the payload interrogator for DOD (because of the COMSEC requirements) and from the payload signal processor for NASA.

b. COMSEC requirements in Tug require the DOD uplinks/downlinks to be routed to the signal processor. Telemetry signals are formatted in the computer interface unit, allowing the NASA downlink to emanate directly from there.

4.2 DEPLOYMENT ADAPTER

The deployment adapter (D/A) comprises the major piece of Tug peculiar Orbiter interface equipment. During ground installation and removal the D/A is treated as an integral part of the Tug. On orbit, the Tug is deployed from the adapter, which remains with the Orbiter until Tug return. The deployment adapter and associated equipment provide the structural, mechanical, fluid, and avionic interfaces between the Tug and Orbiter at the aft end of the cargo bay.

4.2.1 <u>CONFIGURATION DESCRIPTION.</u> The deployment adapter, shown mated to the Tug in Figure 4-2, is a 176-in. (4.47 m) diameter cylinder 74 in. (1.88 m) in length. It contains all Tug-peculiar mechanisms required for transfer of Orbiter/ground services and support of deployment, retrieval, and abort operations. Because the deployment adapter is a cylindrical structure to provide efficient axial load distribution, a rotational deployment feature is incorporated to allow Tug removal during deployment without infringing on the Orbiter cargo bay volume available for Tug

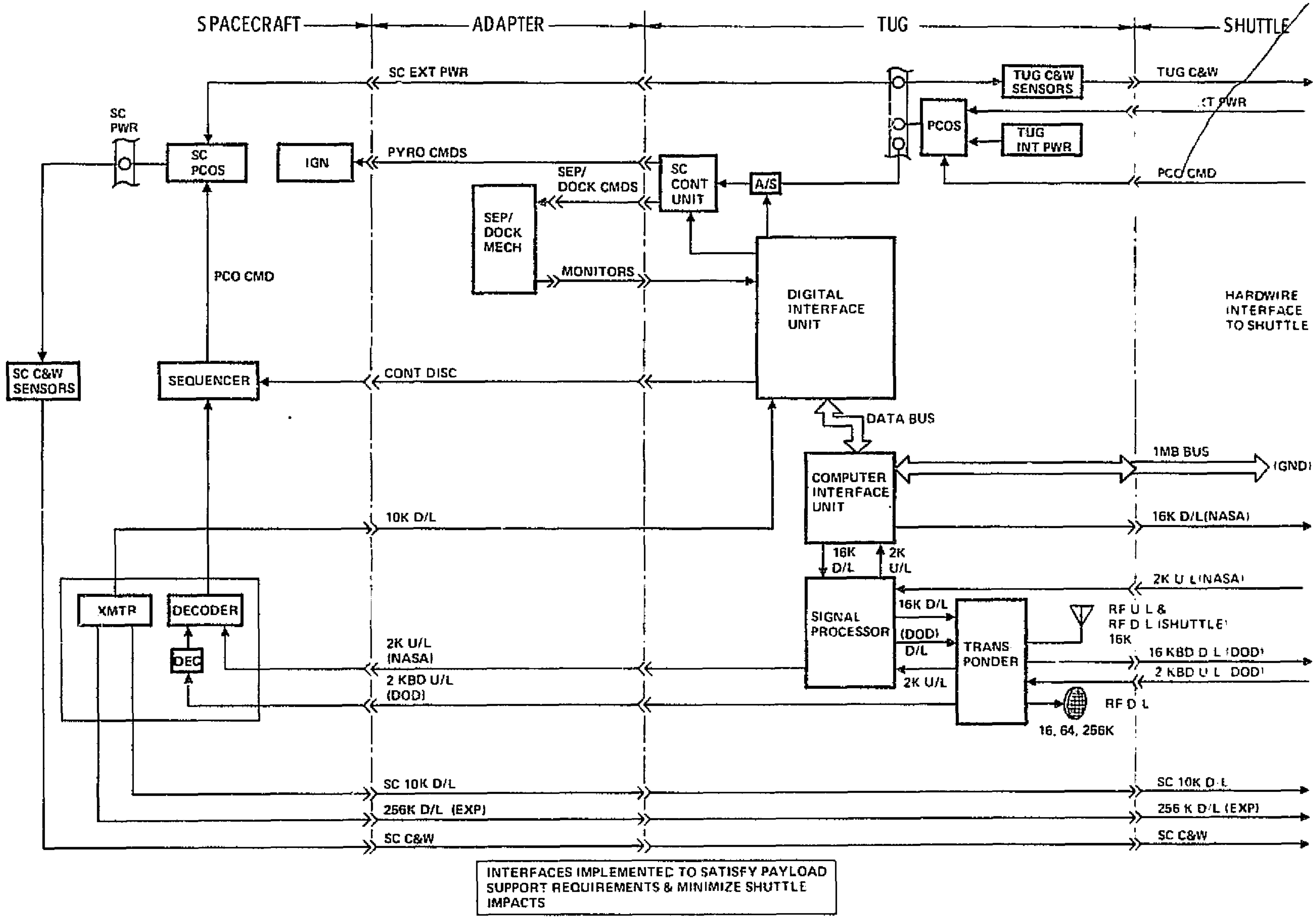


Figure 4-6. Payload-Tug-Shuttle Interfaces

payloads. By using the deployment adapter concept, Tug umbilical and deployment mechanisms can be attached and checked out before Tug installation into the Orbiter. The entire Tug, adapter, and umbilical support are installed as an autonomous unit into the Orbiter. Each major D/A interface subsystem is addressed in the following paragraphs to develop and describe the deployment adapter configuration.

STRUCTURAL. The deployment adapter is a significant element of the Tug's redundant six-point structural support system. The three aft supports (two X/Z and one Y) are located on the Tug deployment adapter. The D/A cylindrical structure provides distribution of the point axial (X) Orbiter support loads into the Tug shell, and serves as a convenient mounting location for other support/servicing equipment. The D/A shell is structurally and geometrically similar to the reference Tug body structure. The initial concept for the deployment adapter was discussed in Vol. II, Section 4.2.3.5. This section summarizes the detailed assessment and special emphasis tasks.

The basic composite sandwich sidewall construction concept was retained from the initial design, but incorporation of the latest X-longeron design and relocation of its associated kick frame resulted in the revised cross-section schematic, frame/shell joint locations, and sidewall flat pattern shown in Figures 4-7, 4-8 and 4-9 respectively.

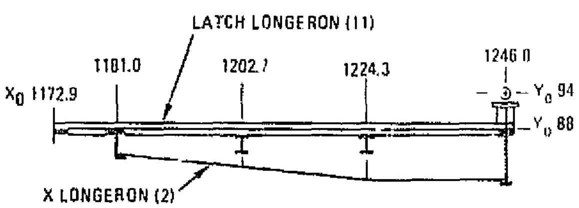


Figure 4-7. Adapter Sidewall Cross Section Schematic

The sidewall sandwich facings were increased in thickness to accommodate the axial load and shear flow peaking effects identified during the finite element analysis (Vol. II, Section 4.2.3.1). Delta thickness and extent of facing reinforcement were based on the body sidewall reinforcement maps shown in Vol. II, Section 4.2.3.10.

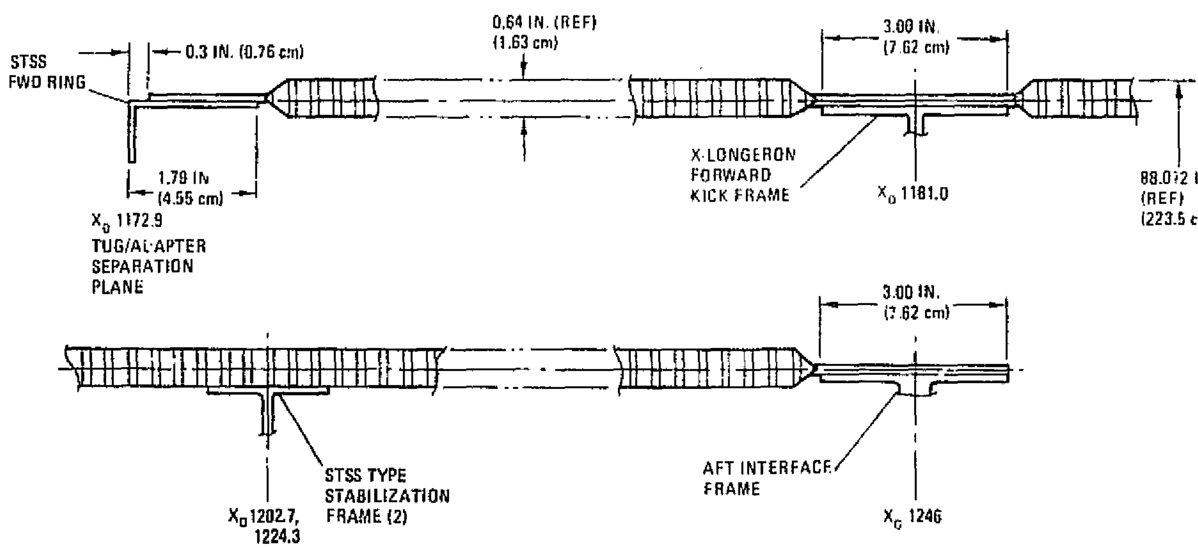


Figure 4-8. Adapter Frame/Shell Joints

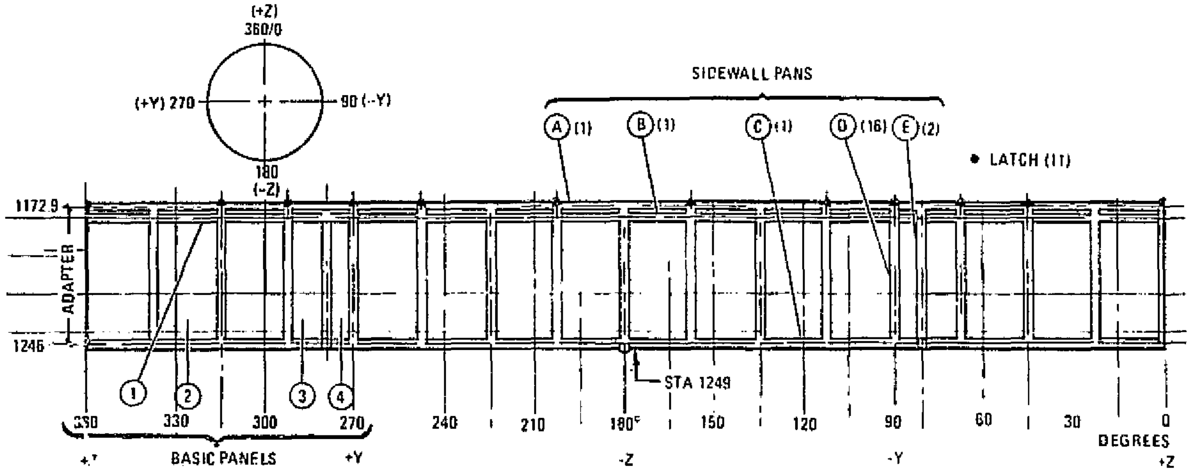


Figure 4-9. Deploy Adapter Flat Pattern

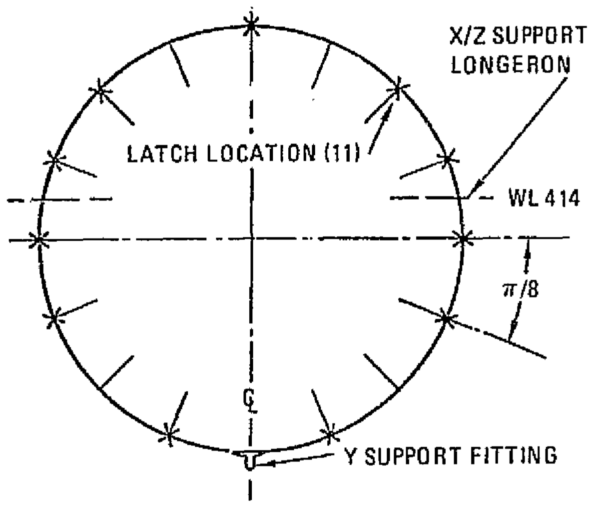


Figure 4-10. Deployment Adapter Latch Longerons

The kick frame for support of the forward end of the X longeron was relocated from X_O 1197.5 to X_O 1181.0. This relocation permitted mounting the aft Y-support fitting on the same frame and reduced the longeron kick loads somewhat due to the span increase. A second lightweight stability frame was then added between the kick frame and the X_O 1246 aft interface frame, and the two frames were located to provide equally spaced shell intermediate support. The X_O 1181 location for the Y support, initially chosen during the alternative X/Z support studies discussed in Vol. II, Section 4.2.3.7, has been retained in the current adapter concept despite the renewed candidacy of the X_O 1249 Y-support location. The latch longeron quantity (11) shown in Figure 4-10 and area requirements were based on the loads and arrangements discussed in Vol. II, Section 4.3.2.10.

The major frames (at X_O 1181 and X_O 1246) employed the reference configuration construction (solid laminate graphite-epoxy), but the X_O 1181 frame was limited to a 6 inch (15.2 cm) depth and revised to a J cross section to provide adequate oxidizer tank support strut clearance. The support fitting and friction stabilization bracket configurations were based on the design updates discussed in Vol. II, Sections 4.2.3.3 and 4.2.3.2 respectively.

Mass properties for the updated adapter are presented in Section 4.5 and include, in addition to the major components discussed above, subsystem support provisions, sidewall facing tolerance and potting allowances, and an appropriate contingency.

MECHANICAL. The deployment adapter has mechanisms associated with structural support, fluid/avionics servicing, and deployment retrieval as shown in Figure 4-11.

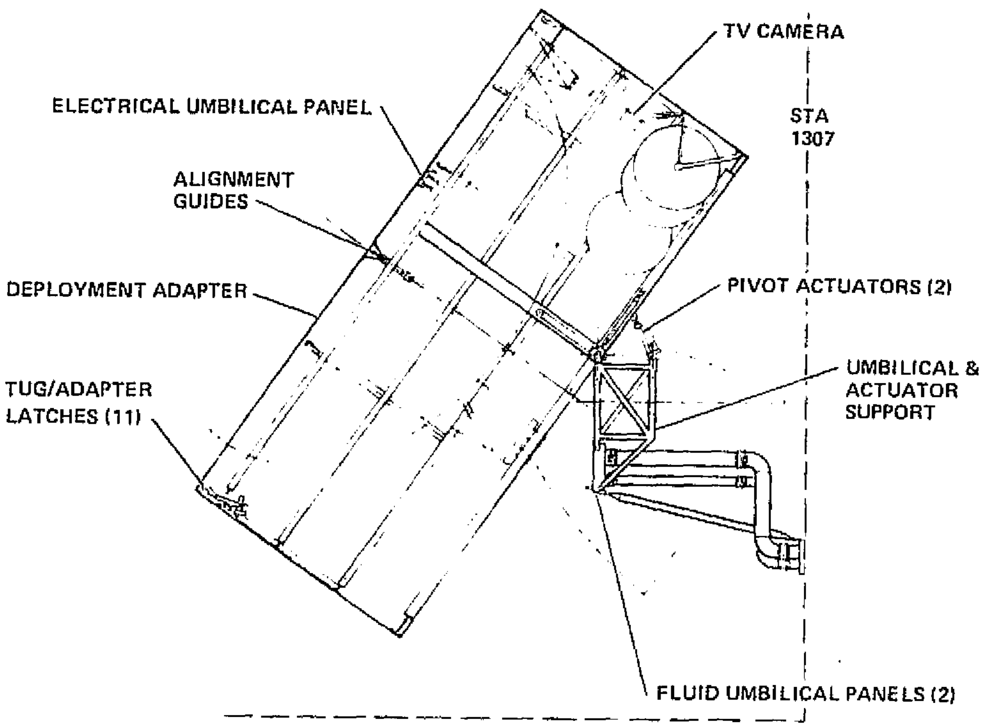


Figure 4-11. Recommended Deployment Adapter Mechanisms

The D/A is shown here in its rotated 35-degree Tug deployment/retrieval position. Rotation occurs about the two primary X/Z support fittings at X_O 1246/Z414. Specific deployment adapter mechanisms are umbilical panels, pivot actuators, Tug-adapter latches, alignment guides, and a TV camera for interfacing between Tug and Orbiter. These individual mechanisms do not directly interface with Orbiter and comprise an integral part of the deployment adapter. Each major device is described in the following paragraphs.

Aft Umbilical Panels. Fluid and electrical services must be attached to the Tug through separable connections capable of reengagement to enable deployment and retrieval for mission achievement. The selected umbilical panel configuration, shown in Figure 4-12, consists of individual supports for the fuel and oxidizer services. These supports are pivot mounted from the deployment adapter support axis, which enables close alignment control of the panels for reengagement, independent of Orbiter to Tug deflections/ tolerances. The Tug-adapter interface is precisely aligned through close tolerance shear pins, which will realign the Tug to the disconnects well within the recommended ±1.18 inch (3.0 cm) side capability of the umbilical panel alignment pins.

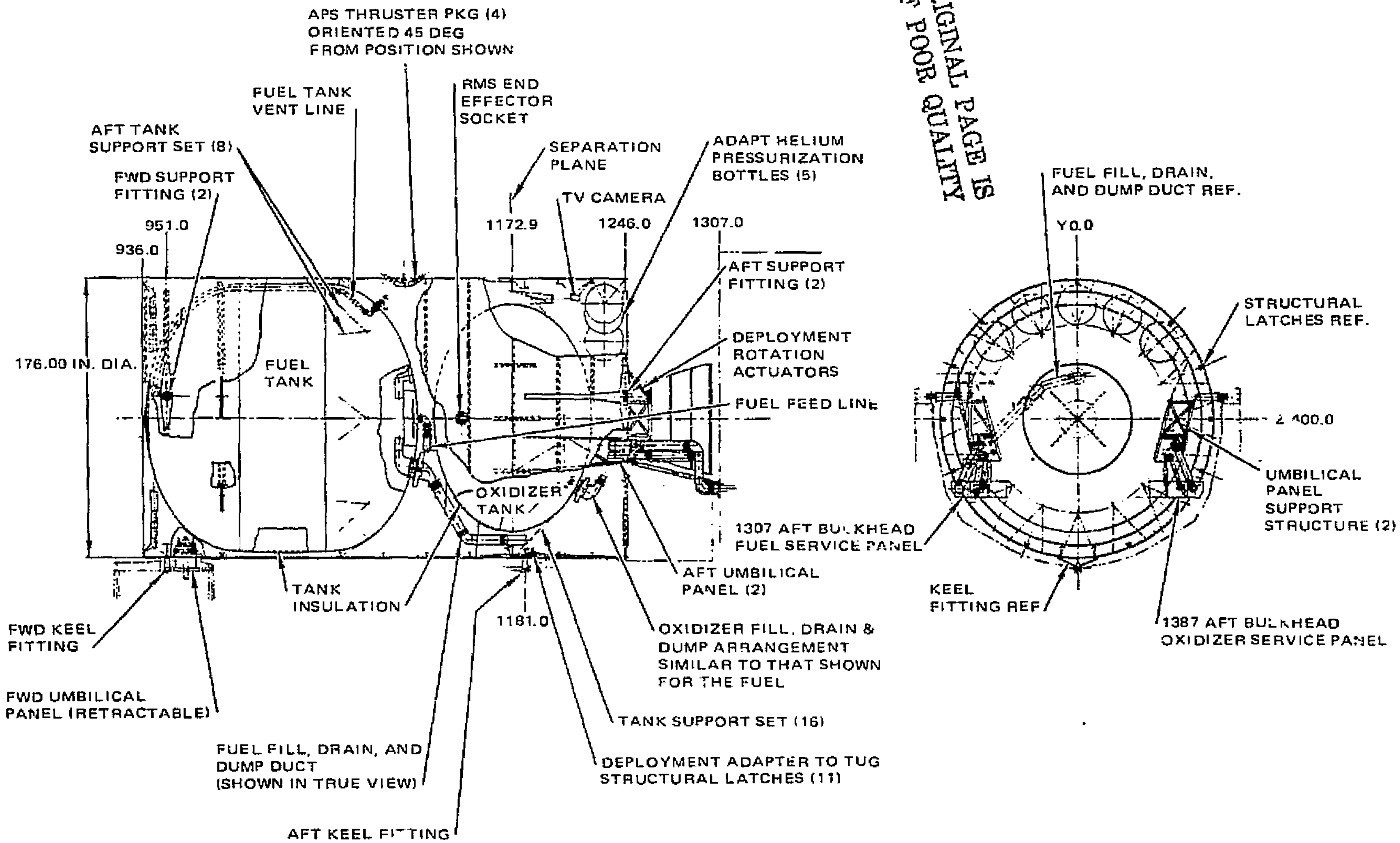


Figure 4-12. Umbilical Panel Configurations

Axial position of the umbilical panels is maintained by struts attached to the Orbiter Station 1307 fluid interface panels. The specific mounting technique and location chosen provide adequate alignment and acceptable forces to enable the deployment adapter pivot actuator to disengage and reengage the umbilicals simultaneously with deployment adapter rotation. Avionics command and control functions (including caution and warning safety data) are not routed through these aft umbilical panels. The disconnect panel(s) containing these functions is located at the adapter/Tug interface (Z_0 1172.9), and electrical umbilicals are routed around the deployment adapter pivot and remain connected until the RF link is established following rotation. The adapter-mounted electrical umbilicals use the excess force available from the Tug to deployment adapter structural latches to provide separation and reengagement.

Pivot Mechanism. The deployment adapter structural support configuration requires initial Tug rotation to provide the axial clearance for lateral extraction of Tug and its engine nozzle from the adapter. Functions provided by the pivot mechanism are:

a. Rotate adapter, Tug and spacecraft for deployment.

b. Hold deployment adapter in position during deployment.

c. Rotate deployment adapter less Tug into cargo bay as required for Orbiter space operations.

d. Hold deployment adapter in stowed position for entry and landing following expendable Tug mission.

Twin actuators, shown in Figure 4-13, mounted between the umbilical panel support structure and the deployment adapter, perform these functions. Actuator requirements are listed in Table 4-2. The redundant actuators, powered simultaneously to effect rotation, are both located on the fuel side (port) umbilical support so that the RMS, when equipped with a special end effector, may be used to disconnect either actuator in the event of failure.

Tug Adapter Latches. Structural latches are required between the Tug and deployment adapter to carry the loads incurred during ground and flight mission phases. As discussed in the structural D/A configuration description, 11 support latches located at $\pi/8$ radian increments are employed as shown in Figure 4-10.

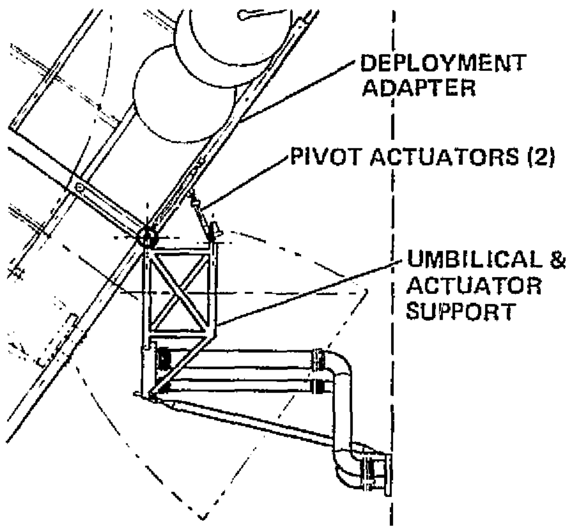


Figure 4-13. Pivot Actuators

Table 4-2. Pivot Mechanism Requirements

Requirement	Selected Concept
Actuator Type	Linear Actuator
Power Source	Electrical
Number of Actuators	Two
Location	Both on Left Side
Position Lock	In Actuator

General requirements for the latch are outlined below and combined in the predesign arrangement shown in Figure 4-14.

a. To distribute loads from the latch to the structural shells of the Tug and adapter, longeron fittings are required at each latch.

b. Present estimates are for a limit latch load of 20 klb (89 kN) each.

c. Shear pins are required for side load transfer between the Tug and adapter.

d. The latch must have a positive force capability to push the Tug away from the adapter. This force must be applied to disengage the shear pins and electrical umbilical, and act over an approximate 0.4 in. (1.0 cm) stroke.

e. For reconnection following RMS retrieval, a pull-together capability of approximately 0.8 in. (2.0 cm) is required to provide terminal alignment, engage the shear pins and electrical umbilicals, and provide latch preload.

f. Structural redundancy for fail safe operation is obtained through multiple latches; i.e., adequate load capability exists if any one latch fails to carry load.

g. High reliability of operation is obtained by using electrically redundant motor configurations in each latch actuator.

h. In event of mechanical jamming that prevents unlatching by the electric motor, the motor support arrangement allows manual unlatch by removing a screw accessible from the exterior of the deployment adapter. Removal of the same screw allows latch overtravel to get the separation cam out of the way for remate and landing in event of actuator failure during retrieval.

Docking Alignment Guides. The Tug is reinserted in the deployment adapter by using the RMS, which has a position accuracy of approximately ±3 in. (7.5 cm). Since

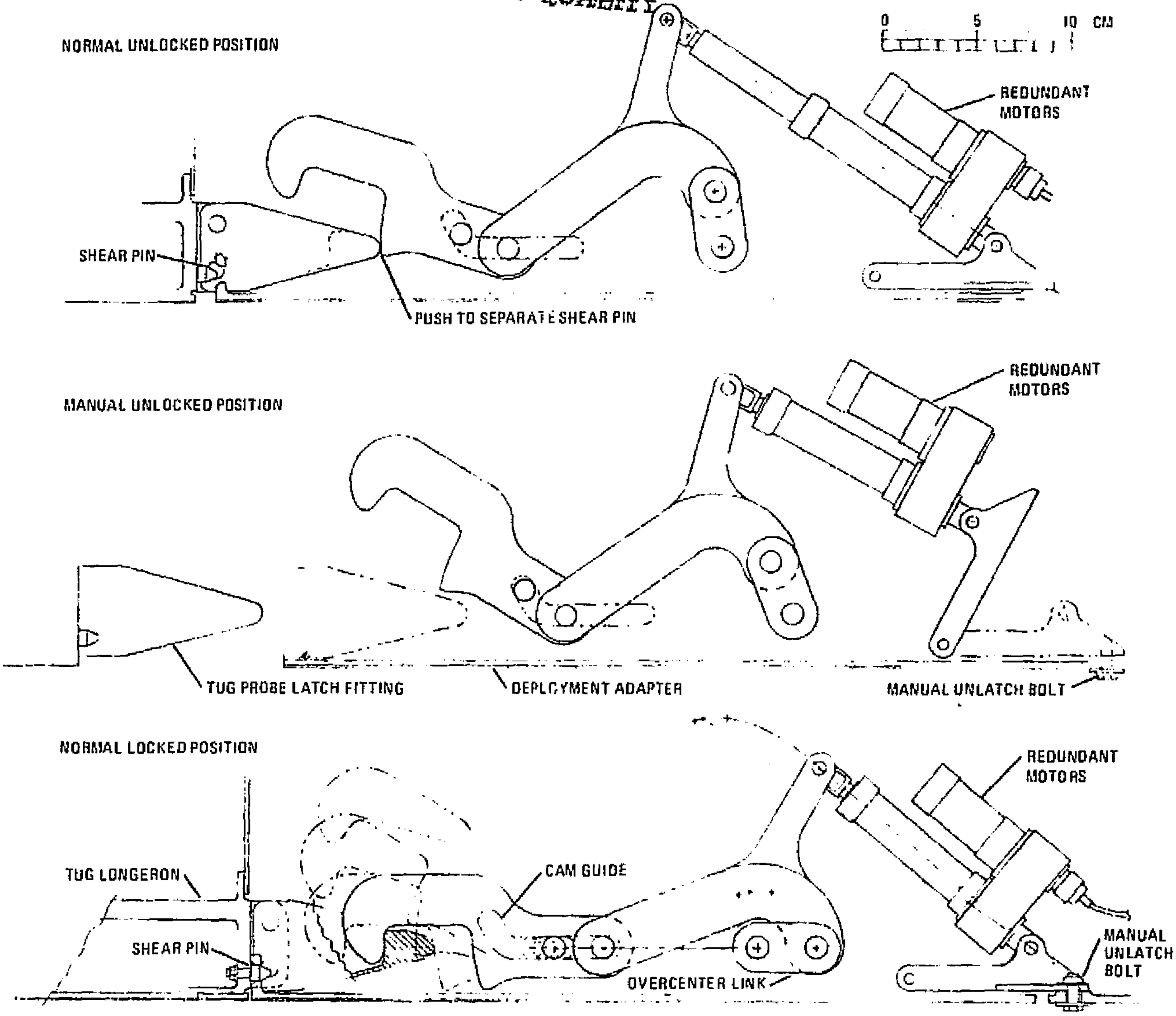


Figure 4-14. Tug Adapter Latch

terminal positioning of ±0.19 in. (0.5 cm) is needed for shear pin engagement, alignment guides must be provided. The guides also give protection from accidental interference of equipment during deployment. A staged or progressive alignment guide is proposed for docking as follows:

Initial RMS alignment of Tug with D/A is aided by a deployment-adapter mounted, Orbiter-supplied TV camera. This camera, which views a suitably located target attached to the aft portion of Tug, enables the Orbiter payload handler to align and position Tug within the RMS ±3 in. (7.5 cm) capability. The Tug umbilical panel supports and the docking aid supports enter the deployment adapter 60 and 30 in. (150 and 75 cm) respectively before docking and are located to enter with up to 6 in.

(15 cm) radial misalignment. The positions of the supports cause the Tug to align within ±0.8 in. (2.0 cm). The probe and guide portion of the Tug-adapter latch engage at 3 in. (7.5 cm) from docking and effect alignment to less than ±0.19 in. (0.5 cm) error. The tapered end of the shear pins engage and, provided with the latch pull-up force, effect final Tug to adapter alignment.

FLUIDS. The deployment adapter provides for transfer of Tug fluids during prelaunch tanking, ground and ascent venting, and in the event of Orbiter abort. It also contains the abort dump helium pressurant and associated pressurization system controls. The D/A fluids schematic is included with the Tug's schematic in Figure 4-3.

The ten through-adapter service lines shown in Figure 4-3 are listed with their diameters in Table 4-3. Line routing, placement of omega joints, and umbilical disconnects are shown in Figure 4-2.

The D/A abort helium system contains 60.3 lb (27.35 kg) of helium, stored in five spherical bottles at 3200 psi (2200 N/cm^2). The distribution system provides this helium to Tug propellant tanks to permit propellant dump during abort, or for tank purging/safing following Tug retrieval after completion of a successful mission. The D/A pneumatic system also provides control of adapter-mounted valves (GH_2 ground or in-flight vent selection and dump line shutoff) and panel purges.

Table 4-3. Through Adapter Fluid Services

Function	Diameter (in.)	Diameter (cm)
LH_2 Fill, Drain & Dump	5.0	12.7
GH_2 Vent (Prelaunch)	3.0	7.6
GH_2 Vent (In-Flight)	2.5	6.4
Fuel Tank Leakage Vent	0.75	1.9
N_2H_4 Drain & Relief	0.5	1.3
LO_2 Fill Drain & Dump	4.0	10.2
LO_2 Topping	0.75	1.9
GO_2 Vent	2.0	5.1
Oxidizer Tank Leakage Vent	0.75	1.9
Helium Service	0.38	0.97

AVIONICS. Major avionics elements associated with the Tug deployment adapter include the deployment adapter interface unit; valves and actuators associated with the control of propellants, fluids and gases; deployment interface hardware; instrumentation; and the deployment adapter power control unit. The deployment adapter interface unit includes redundant command decoder, command distributor, and a downlink data multiplexer units (PCM TLM). This equipment is illustrated in the functional block diagram of Figure 4-15 and described in Table 4-4.

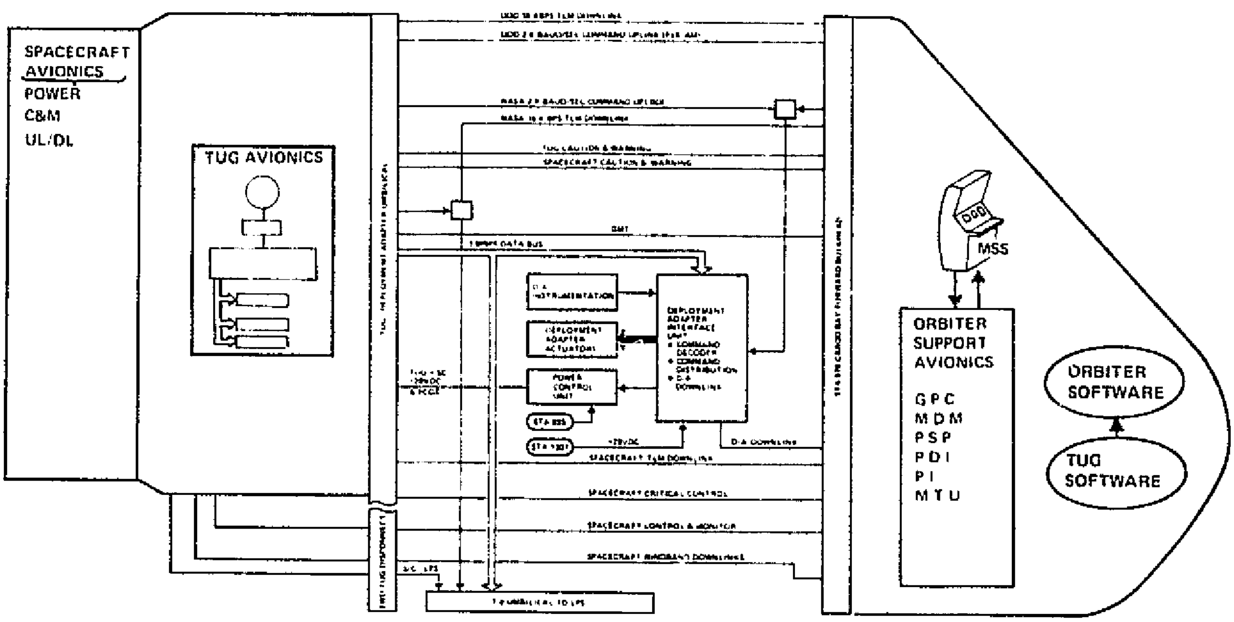


Figure 4-15. Deployment Adapter Interface Diagram

4.2.2 INTERFACE REQUIREMENTS. The deployment adapter interface requirements associated with Tug, Orbiter, and to a lesser degree, Tug payloads all have been implicitly discussed in the preceding section. Table 4-5 identifies these requirements within their appropriate system interface category for Tug, Orbiter, and where applicable, Tug payloads.

4.3 CREW COMPARTMENT EQUIPMENT

The crew compartment Tug support avionics consists of three categories of equipment: 1) Tug-unique man-machine interface equipment consisting of three control panels and associated electronics and cabling, 2) Orbiter-supplied man-machine interface equipment located at the MSS, and 3) Orbiter-supplied payload support avionics.

Tug use of Orbiter avionics equipment located at and associated with the Mission Specialist Station (MSS) includes Orbiter-supplied CRT and keyboard, associated

Table 4-4. Tug Cargo Bay Avionic Equipment

Requirement	Capabilities	Supplier	Location	Power (watts)
Deployment Adapter Interface Unit	Tug/Orbiter avionics; I/F.	Tug	D/A	75
Command Decoder & Distributor	Decode D/A commands from Orbiter 2k baud Bi-Ø-L uplink (redundant).			
D/A PCM Downlink	Format & transmit D/A PCM data to Orbiter PDI (redundant).			
Instrumentation	Monitor D/A controls actuators and safety functions.	Tug	D/A	75
Power Control Unit	Control prime & backup power to Tug/SC, and Tug PCOS.	Tug	D/A	200 (pk)
Actuators	Control of D/A abort, deployment & capture functions.	Tug	D/A	See Note
He Valves				See Note
Rotary Deployment				355
Capture Latches				448
D/A Junction Box	Cable & signal routing terminal for Tug & S/C to Orbiter interface.	Tug	D/A	-
S/C Junction Box	Optional cable & signal routing terminal for S/C interface.	S/C	D/A	-
Forward Junction Box	Optional S/C wiring terminal for spacecraft functions.	S/C	Fwd. Discon.	-

Note: Power requirements are mission-phase dependent. Reference Vol. II, Tables 4.6-11 and 4.6-12.

alphanumeric display electronics, and Orbiter C&W display devices. Tug-provided unique equipment required in the aft crew area includes Tug's two operations control panels located at the MSS and one control panel at the payload handling station (PHS) for control and monitoring of Tug validation, deployment, and activation functions.

4.3.1 TUG SUPPORT HARDWARE. The Orbiter payload support avionics available and used for the Tug/Orbiter interface includes the payload interrogator (PI), payload signal processor (PSP), C&W electronics, master timing unit (MTU), payload data

Table 4-5. Deployment Adapter Interface Requirements

Interface	Tug	Orbiter	Payload
<u>Structural</u>			
Primary Support	11 latches at the 176 inch (4.47 m) dia interface at X_O 1172.9	(2) X/Z @ X_O 1246, Y ±94, Z 414 (1) Y @ X_O 1181, Z 306	
Secondary Support		Struts from umbilical panels to Station 1307 fluid service panels	Mounting of RTG water boiler cooling kit
<u>Mechanical</u>			
Pivot		Z_O 1246 X/Z supports	
Latches	11 @ Z_O 1172.9 release, push apart, draw together, and positively latch		
Umbilical Panels	Fuel fluid service panel – 4 lines	1307 fuel fluid service panel – 5 lines	Shared functions
	Oxidizer fluid service panel – 5 lines	307 oxidizer fluid service panel – 4 lines	Shared functions
	Electrical services	Side body panel – 1 line	
	Hold disconnects engaged against fluid press loads	Hold disconnects engaged against fluid press loads	
	Provide flexibility for flight deflections	Provide flexibility for flight deflections	
	Disconnect services for deployment	Easy installation/removal on ground	

Table 4-5. Deployment Adapter Interface Requirements (Contd)

Interface	Tug	Orbiter	Payload
	Align and reconnect following retrieval		
Alignment Guides	Guide during deploy/retrieval Umbilical supports Latches Taper pins		
TV Camera	Aft target	PHS viewing of D/A-mounted camera	
<u>Fluids</u>			
Propellant Fill, Drain & Dump	LH_2 & LO_2	LH_2 & LO_2	
Prop Vent	GH_2 & GO_2	GH_2 ground, GH_2 inflight, GO_2	Battery vent
Tank Leakage Vent	Fuel & oxidizer tank	Fuel & oxidizer tank	
APS Drain & Relief	N_2H_4	N_2H_4	N_2H_4
Prop Topping	LO_2	LO_2	
Press Service	GHe	GHe	
<u>Avionics</u>			
Power	2340 W (Tug & S/C)	2340 W (Station 695) 781 W (Station 1307)	700 W (via Tug)
Uplink (DOD)	2 TSP	2 TSQ	Via Tug

Table 4-5. Deployment Adapter Interface Requirements (Contd)

Interface	Tug	Orbiter	Payload
Downlink (NASA)	2 TSP	14 TSP	12 TSP
Downlink (D/A)	–	8 TSP	–
Time Code	1 TSP	1 TSP	–
Caution & Warning	3 TSP	38 TSP	35 TSP
GSE Downlink	2 TSP	8 TSP	6 TSP
GSE Data Bus	2 TSP	2 TSP	
Misc S/C (Via D/A)	–	74 TSP	74 TSP

interleaver (PDI), payload multiplexer-demultiplexer (MDM), and limited use of the Orbiter's general-purpose computer system, data recorders, and communication system. The equipment and interface specifications affecting its use are described in document JSC-07700, Section 14 (Revision C, Change 7).

All Orbiter payload support equipment associated with the Tug/Orbiter interface is redundant except for the payload data interleaver and the PCM recorder unit. In addition, all Tug avionic functions employ dual redundancy to achieve operational reliability. In like manner, all major uplinks and downlinks associated with the Tug/ deployment adapter/Orbiter interface are redundant (and use the corresponding redundancy associated with the Tug and Orbiter interface avionics unit). A summary of the required interface hardware is presented in Table 4-6.

4.3.2 TUG SUPPORT SOFTWARE. Software located within the Orbiter's rapid access and mass storage memories also falls into two categories: the Orbiter-supplied operating system and Tug-unique software programs executed by the Orbiter's GPC. The Tug-unique software consists of five categories of software programs (Table 4-7), which operate as application programs under the executive operating systems associated with the Orbiter general-purpose flight computer operating system (FCOS).

The data in the table indicates that the total mass storage required from the Orbiter is approximately 11k words. During normal operations, however, only two programs will operate simultaneously: 1) Tug critical function monitor, and 2) the program associated with the current operational event (i.e., rotate D/A up). Thus, actual working computer memory requirements should not exceed 5k words (program and data base) at any one time. These software estimates assume that the Orbiter GPC has a provided software operating system and a crew/operator interface compatible with Tug-unique software requirements.

A summary of the Tug-unique software requirements and ground rules associated with the Orbiter GPC system is presented in Table 4-8. It should be noted that the five Tug-unique software program categories may be divided into two groups consisting of 1) safety-critical programs and 2) nonsafety-critical programs. These two groups may reside in separate regions of the GPC system; however, it is required that the safety-critical programs (category 100, real-time monitor) be continually in residence in the redundant GPCs.

4.4 CARGO BAY UMBILICAL KITS

Kits for transmitting Tug and Tug payload fluid and electrical services within the Orbiter cargo bay are required. Routing and panel interface requirements for these services are described in this section. Tug payload service needs vary considerably and are covered separately in Section 3 of Volume II.

Table 4-6. Tug Aft Cabin Equipment Requirements

Requirement	Categories	Supplier	Location	Power (AVE)	Wt, lb (kg)	Panel Space, in. (cm^2)
Data Control Processor	Real time, time shared, 16 bit word, 20 kops, dedicated use all mission phases, redundant.	Orbiter	GPC	See Note	See Note	See Note
TLM Decom	PCM decoder, two channels (redundant) at 16 kbps, data accessible by payload software.	Orbiter	PSP, PDI, Master PCM Unit			
I/O	IME Code: GMT accurate to 1 ms; 30 discrete. Inputs and outputs to aft crew cabin.	Orbiter	MTU MDM			
Software	Tug support executive software control of five S/W categories:	Tug/ Orbiter	GPC			
Application S/W	Real time monitor/C&W Initialization/status Deploy/capture RF communications Utility & control					
Common Storage	TLM tables, interface tables					
Data Storage			GPC			
Operating Memory	15 k words	Orbiter				
Rapid Access (1 sec)	10.7 k words					
Communications						
Hardwired Uplink	2 k baud/sec, BI - Ø - L (redundant).	Orbiter	PSP			
Hardwired Downlink	16 k baud/sec, two redundant channels (DOD/NASA + D/A).		PSP			
RF	Data processor interface, transmitter/receiver, S-Band DOD/NASA, redundant components.		PI			
Uplink	2 k baud/sec.					
Downlink	16 k baud/sec.					
Crew Interface	CRT & keyboard (redundent).	Orbiter	MSS			
Panels	C&W electronics & annunciators.	Orbiter	MSS			
	Tug master caution/warning lights.	Tug	MSS	10	1(.45)	3 (20)
	Tug deployment/capture panel.	Tug	PHS	20	4(1.8)	23 (148)
	Tug initialization & safing panel.	Tug	MSS	20	6 (2.7)	48 (310)
	Tug abort control panel.	Tug	MSS	20	4 (1.8)	23 (148)
	Tug panel control electronics.	Tug	MSS	30	5 (23)	0

Note: Orbiter supplied standard payload support equipment, reference NASA Doc. No. JSC-07700, Vol. XVI or applicable NAR specification.

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Table 4-7. Tug-Unique Orbiter Support Software

ID	Tug Support Software	Memory	Speed (Avg)
100	Tug real-time monitor	850	1.0 kOPS
200	Tug initialization, status	4,890	0.03
300	Tug deploy/capture	200	0.01
400	Tug RF control	2,225	0.1
500	Tug utility & control	505	0.5
Data Base	Common storage, tables, etc.	1,500	
TOTALS		10,170	2.0 kOPS

Table 4-8. Ground Rules for Use of Orbiter GPC Software

10 k words (32-bit) memory allocation (half word instructions — OK)

18 k adds/sec (time continually available)

Orbiter provided library (math) routines

Orbiter provided display formatting software (payload software will input to this)

Mass memory available for program roll-in (accessible within 1/2 to 8 seconds on command from payload software)

Keyboard, CRT available to payload

External PCM decommutation of:

- 16 kbps Tug bit stream (through payload signal processor)
- 16 kbps deployment adapter bit stream (through payload data interleaver)

Spacecraft status monitoring and command programs provided by spacecraft user

GPC has backup input to C&W annunciator

Safety-critical data monitor software is resident in the GPC system continually, and cannot be superseded.

Nonsafety-critical data functions are grouped separately

Since Tug fluid kits are included as part of the deployment adapter, the only separate kits are those for monitor and control electrical wiring, Tug power, and the forward umbilical panel disconnect mechanism and lines. The forward umbilical panel mechanism is described in Section 2 of this volume.

4.4.1 PANEL REQUIREMENTS — FLUIDS. The Orbiter provides interface panels at the aft payload bay bulkhead (1307 panels) and on the sides of the aft fuselage (T-0 panels) for Tug and payload fluid services. These panels along with possible arrangements of the required fluid lines are depicted in Figure 4-16. Panel locations and space allocated are compatible with the Tug requirements. Detail design performance requirements at the 1307 panels are given in Tables 4-9 and 4-10. The line numbers indicated on the interface panels correspond with the interface data requirements identification numbers on the two tables.

Tables 4-9 and 4-10 summarize the significant design requirements for the Tug service lines at the 1307 oxidizer interface and fuel (I/F) panels. The selected diameters given are those of the service lines forward of the 1307 panels. The "design condition" data allows determination of Orbiter service line design requirements for compatibility with Tug requirements. This data should be interpreted as follows:

a. Orbiter-to-Tug Flow. The Orbiter should provide fluid at flow rate and pressure equal to or greater than specified and a temperature equal to or less than specified.

b. Tug-to-Orbiter Flow. The Orbiter should accept fluid at flow rate and temperature equal to or greater than specified at a pressure equal to or less than specified.

All design condition data are for an Orbiter/Tug acceleration of 1.0 g.

4.4.2 SERVICE ROUTING — AVIONICS. The electrical service routing implementation for the spacecraft, Tug, deployment adapter, and Orbiter are shown in Figure 4-17 and listed in Table 4-11. The various Tug and spacecraft interface functions are grouped according to function and identified by code numbers. Tug and payload C&W, safing control and on-orbit power functions (Codes 5, 3, 8, and 9) are routed through the Tug deployment adapter through the Orbiter aft cargo bay bulkhead at station 1307, thus providing hardwired control during all attached operations including predeployment and post-capture. A forward Tug disconnect (Code 4) is provided near station 961 for on-orbit and prelaunch checkout of Tug-spacecraft. This umbilical interface provides payload access to the Orbiter, T-0 umbilical panels and the T-4 umbilical panels with minimum weight penalty to the Tug vehicle.

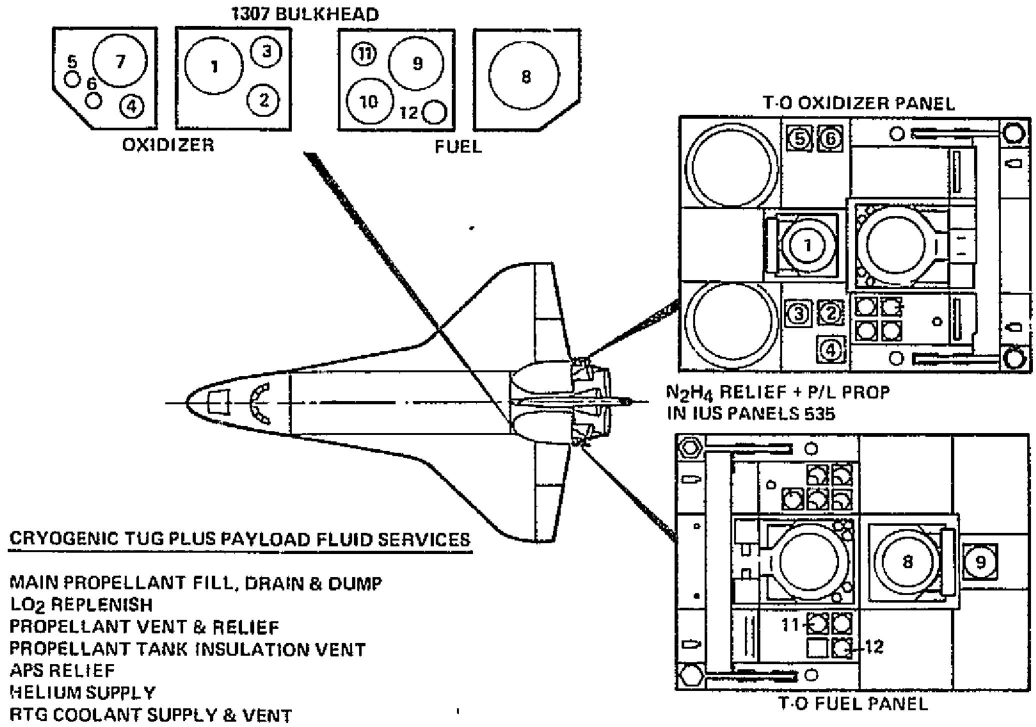

Figure 4-16. Tug/Orbiter Fluid Ir:.:rfaces

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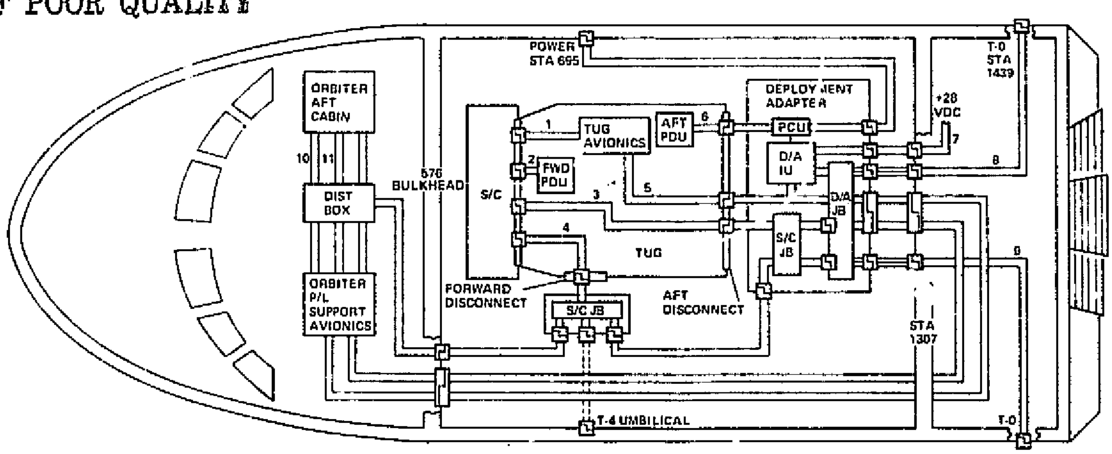

Figure 4-17. Tug Electrical Services Routing

Spacecraft junction box (JB) mounting facilities are provided at both the forward disconnect and on the deployment adapter to allow maximum spacecraft flexibility without adding additional weight to Tug or Orbiter systems. In like manner all Tug, deployment adapter, and spacecraft control and monitor signals are routed through the deployment adapter junction box for distribution to and from standard Orbiter interface

connections at Orbiter station 1307. Redundant Tug (and spacecraft) uplinks and downlinks to ground are shown to be split, with each redundant set of signals routed through the separate T-0 umbilical panels, located on each side of the Orbiter at station 1439.

Power is supplied to the Tug/spacecraft and the deployment adapter through separate interfaces (Codes 6 and 7, respectively). Orbiter dedicated and backup power from station 695 is available to the Tug through the deployment adapter power control unit (PCU) for on orbit-checkout and validation operations, while deployment adapter power (dedicated and backup) is provided through Orbiter station 1307.

Tug and spacecraft control and monitor functions interface with Orbiter payload support avionics via connections at station 576. An Orbiter distribution box provid^r s

Table 4-9. Tug Oxidizer Panel Interface Requirements at Station 1307

LO_2 PANEL	DIA (INCH)		ACTIVE	DESIGN FLOW RATE MIN-MAX	MAX HEAT LEAK	ENVIRONMENT LIMITS INTERFACE PRESS (psia)		TEMP (R)		DESIGN CONDITION FLOW	I.F PRESS	TEMP	AMBIENT PRESS
	SELECTED	REQ	DURING	(lb-sec)	(Btu/hr)	MAX	MIN	MAX	MIN	(lb/sec)	(psia)	(R)	(psia)
1. FILL, DRAIN, DUMP	4 0												
a. FILL		2.0	G	5 30		28 5	14 7	560	163	24.5	28.5	163.25	14.7
b. DRAIN		2.0	G	30	—	28.5	14 7	560	163	24.5	19 0	163.25	14.7
c. ABORT (RTLS)		4 0	G/AS/O	147	—	26 0	0	560	163	147	18.0	163.25	0
2. LEAKAGE VENT	0.75		ALL										
a. FLANGES													
b. PANEL PURGE													
c. CONTAINMENT				0.008		16	0	560	180	0.008	1.0	180	0.8
3. TOPPING	0 75	0 75	G	0 15-2 0	55	35	0	560	163	2.0	33.6	162.7	14.7
4. HELIUM FILL	0.375	0.30	G	0.022	—	3,200	0	560	500	0.022	200	520	14.7
5. RTG WATER IN	0.5	0.5	G	2		60	0	560	520	2	60	520	14.7
6. RTG WATER OUT	0.5	0 5	G	2		50	0	680	600	2	50	600	14.7
7. RTG STEAM VENT	3.0	3 0	AS, O	0.0135		1.25	0	570	560	0.0135	1.25	560	0

LO_2 PANEL	DIA. (cm)		ACTIVE	DESIGN FLOW RATE MIN-MAX	MAX HEAT LEAK	ENVIRONMENT LIMITS INTERFACE PRESS (N/cm^2)		TEMP (K)		DESIGN CONDITION FLOW	I.F. PRESS	TEMP	AMBIENT PRESS
	SELECTED	REQ	DURING	(Kg/sec)	(watt)	MAX	MIN	MAX	MIN	(Kg/sec)	(N/cm^2)	(K)	(N/cm^2)
1. FILL, DRAIN, DUMP	10.16												
a. FILL		5.1	G	2.3-13.6	–	19.6	10.1	311	90.5	11.1	19.6	90.7	10.1
b DRAIN		5.1	G	13.6	–	19.6	10.1	311	90.5	11.1	13.1	90.7	10.1
c. ABORT (RTLS)		10.16	G/AS/O	66.7	–	17.9	0	311	90.5	66.7	12.4	90.7	0
2. LEAKAGE VENT	1.9		ALL										
a. FLANGES													
b PANEL PURGE													
c. CONTAINMENT				0.0036	–	11.03	0	311	100	0.0036	0.67	100	0.55
3. TOPPING	1.9	1.9	G	0.07-0.09	16.1	24.1	0	311	90.5	0.09	23.2	90.38	10.1
4. HELIUM FILL	0.95	0.76	G	0.01	–	2206	0	311	278	0.01	138	289	10.1
5. RTG WATER IN	1.27	1.27	G	0.9	–	41.4	0	311	289	0.9	41.4	289	10.1
6. RTG WATER OUT	1.27	1.27	G	0.9	–	34.5	0	378	333	0.9	34.5	333	10.1
7. RTG STEAM VENT	7.62	7.62	AS, O	0.006	–	0.86	0	317	311	0.006	0.86	311	0

G = GROUND AS = ASCENT O = ORBIT

limited payload capability in routing signals to the aft crew station locations and selected payload support avionics. This configuration does not, however, allow payload unique equipment located in the aft crew station to interface with Orbiter payload support avionics (such as the MDM), thus it is recommended that all payload signals from both the aft crew cabin and cargo bay locations be routed through the Orbiter's payload signal distribution box.

Table 4-10. Tug Fuel Panel Interface Requirements at Station 1307

LH_2 PANEL	DIA (INCH) SELECTED	DIA (INCH) REQ	ACTIVE DURING	DESIGN FLOW RATE MIN-MAX (lb-sec)	MAX HEAT LEAK (Btu/hr)	ENVIRONMENT LIMITS INTERFACE PRESS (psia) MAX	PRESS (psia) MIN	TEMP (R) MAX	TEMP (R) MIN	DESIGN CONDITION FLOW (lb/sec)	I.F. PRESS (psia)	TEMP (R)	AMBIENT PRESS (psia)
8. FILL, DRAIN, DUMP	5.0												
a. FILL		2.0	G	2.0 4.15	—	24	14.7	560	36	4.15	[illegible]	37.0	14.7
b. DRAIN		2.0	G	4.15	—	24	14.7	560	36	4.15	16.3	37.0	14.7
c. TOPPING		0.75	G	0.15 0.25	350	24	14.7	560	36	0.25	23.5	37.0	14.7
d. ABORT DUMP		5.0	G/AS/0	25	—	24	0	560	36	25.0	17.4	37.0	0
9. TANK VENT	3.0												
PRELAUNCH VENT		3.0	G	0.25	—	23	14.7	560	40	0.25	[illegible]	60.0	14.7
10. TANK RELIEF	2.5	2.5	AS/0/RE	0.144	—	20	0	560	40	0.144	15.7	75.0	0.25
11. LEAKAGE VENT	0.75		ALL										
a. FLANGES		0.25											
b. PANEL PURGE		0.5											
c. CONTAINMENT		0.75		0.08	—	16.0	0	560	40	0.08	1.0	100	0.8
12. N_2H_4 FILL, DRAIN & RELIEF	0.375	0.375	G	0.05	—					0.05	25.0	520	14.7

LH_2 PANEL	DIA. (cm) SELECTED	DIA. (cm) REQ	ACTIVE DURING	DESIGN FLOW RATE MIN-MAX (Kg/sec)	MAX HEAT LEAK (watts)	ENVIRONMENT LIMITS INTERFACE PRESS (N/cm^2) MAX	PRESS (N/cm^2) MIN	TEMP (K) MAX	TEMP (K) MIN	DESIGN CONDITION FLOW (K/[illegible])	I.F. PRESS (N/cm^2)	TEMP (K)	AMBIENT PRESS (N/cm^2)
8. FILL, DRAIN, DUMP	12.7												
a. FILL		5.1	G	0.91-1.88	-	16.5	10.1	311	20	1.88	16.2	20.5	10.1
b. DRAIN		5.1	G	1.88	-	16.5	10.1	311	20	1.88	11.2	20.5	10.1
c. TOPPING		1.9	G	0.07-0.11	102	16.5	10.1	311	20	0.11	16.2	20.5	10.1
d. ABORT DUMP		12.7	G/AS/0	11.34	-	16.5	0	311	20	11.34	12.0	20.5	0
9. TANK VENT	7.6												
PRELAUNCH VENT		7.6	G	0.11	-	15.9	10.1	311	22		10.9	33.3	10.1
10. TANK RELIEF	6.4	6.4	AS/0/RE	0.07	-	13.8	0	311	22		10.8	41.7	0.17
11. LEAKAGE VENT	1.9		ALL										
a. FLANGES		0.64											
b. PANEL PURGE		1.3											
c. CONTAINMENT		1.9		0.0036	-	11.03	0	311	22		0.68	55.5	0.55
12. N_2H_4 FILL, DRAIN & RELIEF	0.95	0.95	G	0.023	-	-	0	311	278		17.2	289	10.1

G = GROUND AS = ASCENT O = ORBIT RE = RETURN

In summary, the Tug/spacecraft/deployment adapter electrical service requirements fall within the current Orbiter capability except for the spacecraft requirements for 24 TP cables in the T-0 umbilical. It is recommended that these signals use the spare TSP cable available to satisfy this requirement.

Table 4-11. Tug/Orbiter Interface Cable Kits

Item	Function	From	To
1	Tug/Spacecraft End Power	Orb. Sta. 695	D/A PCU
2	D/A Power	Orb. Sta. 1307	D/A IU
3	Tug/Spacecraft Prelaunch Functions (A1)	D/A J/B	Orb. Sta. 1307
4	Tug/Spacecraft Prelaunch Functions (A2)	Orb. Sta. 1307	Orb. Sta. 1439 (T-O Fuel Panel)
5	Tug/Spacecraft Prelaunch Functions (B1)	D/A J/B	Orb. Sta. 1307
6	Tug/Spacecraft Prelaunch Functions (B2)	Orb. Sta. 1307	Orb. Sta. 1439 (T-O Oxidizer Panel)
7	Tug/Deployment Adapter Digital Uplink/Downlink (A1)	D/A J/B	Orb. Sta. 1307
8	Tug/Deployment Adapter Digital Uplink/Downlink (A2)	Orb. Sta. 1307	Orb. Sta. 576
9	Tug/Deployment Adapter Digital Uplink/Downlink (A3)	Orb. Sta. 576	Orbiter PI, PSP, PDI, MTU Units
10	Tug/Deployment Safety Adapter Monitors (A1)	D/A J/B	Orb. Sta. 1307
11	Tug/Deployment Safety Adapter Monitors (A2)	Orb. Sta. 1307	Orb. Sta. 576
12	Tug/Deployment Safety Adapter Monitors (A3)	Orb. Sta. 576	Orbiter C&W Ele. Units
13	Tug Control Panel Harness	MSS, PHS	Orbiter MDM Units
14	Tug Control Panel Power Harness	MSS, PHS	Orbiter Aft Cabin +28 vdc

4.5 MASS PROPERTIES

The deployment adapter and associated Orbiter-retained Tug chargeable equipment weighs approximately 1801 lb (818 kg). Of this total, 89 percent (or 1600 lb (725 kg)) is included in the deployment adapter. In addition to the structure and mechanisms, all the fluid system and 73 lb (33 kg) of avionics (electronic interface unit, power control unit and cabling) is attached to the adapter. The remaining weight is payload caution and warning hardwires, connections, panels, and support clips.

Tug peripheral equipment weights are itemized in Figure 4-18. In addition to the 1801 lb (818 kg) indicated, two additional Orbiter bridge beams and fittings are required for the selected six-point redundant Tug support system. These beams (one latching Z-only and one Y-only keel fitting, both at station 951), although Orbiter supplied, are payload-weight chargeable at 227 lb (103 kg). Tug peripheral equipment weights do not include Tug service lines connecting the 1307 panels to the T-0 umbilicals. These lines, which pass through the Orbiter engine compartment, are an Orbiter (RI) responsibility and were assumed to be Orbiter chargeable.

	WEIGHT LB	WEIGHT KG
ADAPTER STRUCTURE & MECHANISM	(693)	(315)
GRAPHITE-EPOXY PANELS	220	100
FRAMES	119	54
LATCH LONGERONS	22	10
LATCH MECHANISM (11)	117	53
ORBITER/TUG SUPPORT FITTINGS (3)	143	65
SYSTEMS PROVISIONS & MISC	72	33
UMBILICAL SUPPORT & MECHANISMS	(98)	(44)
SUPPORT & MECH		
UMBILICAL SUPPORT & PANELS	58	26
ADAPTER ROTATION MECHANISM	40	18
FLUID SYSTEM	(737)	(335)
GO_2 VENT	10	5
LO_2 FILL, DRAIN AND DUMP	47	21
LO_2 TOPPING	11	5
GH_2 VENT	61	28
LH_2 FILL, DRAIN AND DUMP	96	44
HELIUM SUPPLY SYSTEM	490	222
SUPPORTS & MISC	22	10
ELECTRICAL & AVIONICS	(273)	(124)
ELECTRONIC INTERFACE UNIT	50	23
POWER CONTROL UNIT	24	11
WIRING & CONNECTORS	164	75
INTERFACE PANELS (2)	12	5
SUPPORTS & MISC	23	10
TOTAL PERIPHERAL EQUIPMENT WEIGHT	1801	818

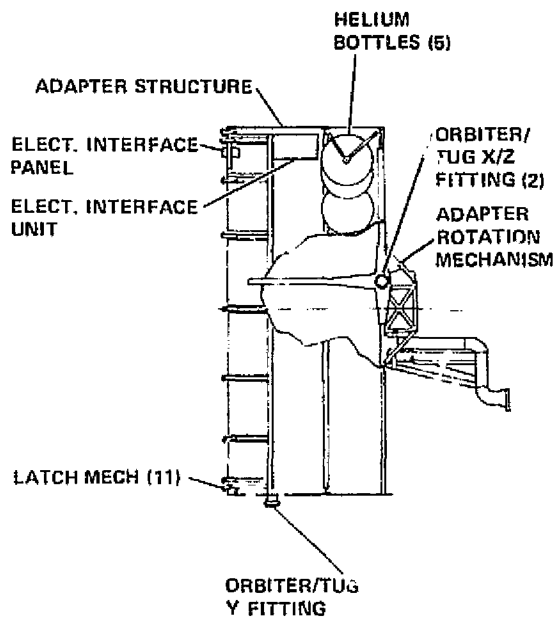

Figure 4-18. Tug Peripheral Equipment Weights

Additional details of the deployment adapter structure weight development is contained in Table 4-12.

An investigation of Tug X-CG location was conducted to determine abort sensitivities. The location of the Tug X-CG while in the Orbiter cargo bay will vary depending on the main propellant load and the spacecraft carried by the Tug. This CG variability impacts the Tug/Orbiter support design and is important in determining the loads at the selected Orbiter support fittings. Other areas affected by Tug CGs are Shuttle stability and control characteristics during reentry and landing, main propellant dump system design, and if dump capability is not supplied, the necessity for static ballasting to bring the Tug X-CG within allowable Shuttle limits.

The X-CG spread possible with the recommended Baseline Tug and its peripheral equipment is illustrated in Figure 4-19. The CG of the fully loaded Tug without a spacecraft (representative of the Tug at liftoff for a retrieval mission) is generally

Table 4-12. Adapter Structural Weight Summary

Item	Weight (lb)	Weight (kg)
Sidewall		
Basic Panels	91.9	41.7
Reinforcement	21.9	9.9
Pans	91.0	41.3
Misc. Potting	9.2	4.2
Skin Tolerance	6.0	2.7
Latch Longerons	22.3	10.1
Frames and Rings		
Fwd, X_o 1172.9	13.0	5.9
Kick, X_o 1181.0	26.2	11.9
Stab., X_o 1202.7	9.8	4.4
X_o 1224.3	9.8	4.4
Aft, X_o 1246	60.4	27.4
Orbiter Support Fittings		
X/Z (2)	129.8	58.9
Y	13.1	5.9
System Supports	37.0	16.8
Structure Sub-Total	541.4	245.8
Contingency	54.1	24.6
Structure Total	595.5	270.4

outside of the aft Shuttle CG limit. To bring the Shuttle CG within limits during landing and abort, at least 85 percent of the main propellants have to be consumed or dumped. The recommended baseline Tug concept provides this dump capability. The middle CG curve illustrates the effect of adding ballast weights at the nose of the Shuttle to improve the CG picture if propellant dump is not provided. The forward CG limit which is of potential concern for large Tug payloads appears to offer no problem, as illustrated by CG travel curve for the 10571 pound (4790) PL-01A spacecraft/Tug case.

Even though Tug propellant dump is the selected method of implementing Orbiter CG control, it is recommended that provisions for mounting ballast weights in the Orbiter nose section, crew compartment and forward Tug/Orbiter support fittings and beams be considered.

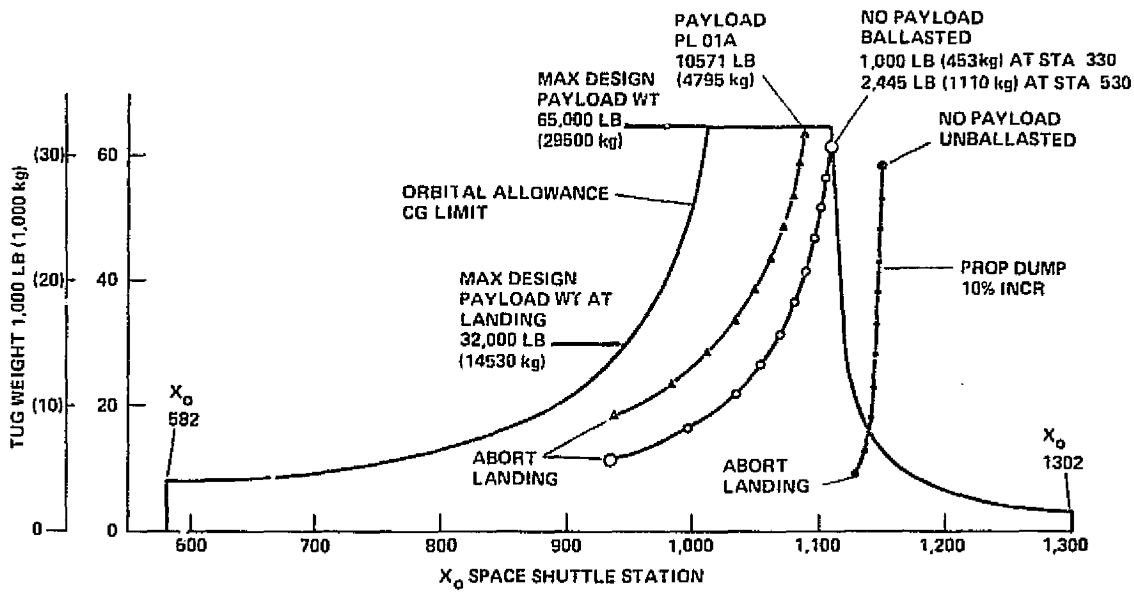

Figure 4-19. Tug Mass Properties and X Center of Gravity

SECTION 5

REQUESTED ORBITER INTERFACE REVISIONS

Orbiter payload accommodations, as identified in JSC 07700 Vol. XIV, Rev. C, were evaluated for their detailed compatibility with the recommended Tug plus payload-to-Orbiter physical and operational interface needs, as identified in Sections 3 and 4 of this volume.

This investigation indicated that, while Orbiter-envisioned payload accommodations are generally compatible with the recommended Tug/Orbiter operational plan and its associated interface requirements, some changes would be desirable for Tug plus its payloads. Twenty-two recommended change requests were prepared by the Space Tug/Shuttle Interface Compatibility Study Team and submitted to MSFC for their assessment and processing as possible Level II changes. Some of these requests were revised several times to reflect interface requirements revisions and MSFC directed modifications.

The interface accommodations affected by these proposed changes are indicated in Table 5-1. Most of these change requests clarify or better describe Orbiter

Table 5-1. Orbiter Interface Change Activity Summary

INTERFACE	CHANGES SUBMITTED TO MSFC	REVISION DESCRIPTION	PROBABLE ORBITER IMPACT
STRUCTURES	3	• IMPROVED DEFINITION OF ORBITER SUPPORT REACTION CAPABILITY	MINOR
MECHANISMS	2	• RMS CONTROL REQUIREMENTS • END EFFECTOR PROVISIONS	MINOR
FLUIDS	1	• IN-FLIGHT VENT/DUMP REQT	MODERATE
ENVIRONMENTAL	1	• PRELAUNCH CONDITIONING EXHAUST & DEW POINT REQTS	MINOR
AVIONICS	7	• ACCESS TO ORBITER DATA BUS • INCREASED C&W PROCESSING • IMPROVED ACCESS TO PAYLOAD SIGNAL PROCESSOR	MINOR TO MODERATE
SERVICE PANELS	4	• IMPROVED SERVICE SPECS	VERY MINOR
SERVICE ACCESS	2	• 1307 PANEL RELOCATION • RACEWAY SPACE FOR FWD PAYLOAD KEEL UMBILICAL	MAJOR MODERATE
OPERATIONS	2	• C&W ON ORBITER SUPPLIED EQUIP • THRUST REQT FOR ABORT DUMP	VERY MINOR MINOR

accommodations already identified in JSC 07700, Vol. XIV. Several of the avionics change requests asked for expanded payload use of Orbiter supplied equipment. Table 5-2 lists these proposed changes in their order of preparation by GDC identification number. The specific interface revision requested by each of these changes is presented in this section by its GDC identification number. SI units were not included in these change requests for their MSFC submittal and have not been added here. Details investigated and options considered for request preparation are included in the appropriate subsystem analyses and trade study presentations in Section 4, Volume II.

Change request references to section, figure, table and/or paragraph number apply to the "Space Shuttle System Payload Accommodations" document, JSC 07700, Vol. XIV, Rev. C.

5.1 GDC 001, GN_2 PURGE REQUIREMENTS

CHANGE TITLE:

Space Tug/Payload Cargo Bay GN_2 Purge Flow Requirements During Propellant Loading and Countdown.

DESCRIPTION OF CHANGE:

Section 4.2.1.2, B.*,a. Size check valves (vents) in the aft bulkhead at station X_o 1307 to accommodate a minimum of 115 lb/min GN_2 purge gas flow during Tug propellant loading and final terminal countdown (see attached Figure 5-1). Bias, or program the LH and RH vent shown in Figure 4-4* forward of station X_o 1128 (reference Section 4.2.2.1)*, to remain closed during this time. The LH and RH vent at X_o station 1128 is to be opened only when minimum of 115 lb/min GN_2 is flowing through station X_o 1307 bulkhead. All additional purge flow to exit only from X_o station 1128 vents. Dew point of GN_2 purge gas to be -76F maximum.

REASON FOR CHANGE:

Incorporation of this capability in the payload bay purge system, combined with a GN_2 purge gas flow at approximately 140 lb/min. at a temperature of 59F to 69F inlet, will ensure maintaining spacecraft surface temperatures within acceptable limits based upon SSPD data. In addition, this combination of inlet GN_2 purge gas flow rate and temperature, Figure 5-2, will also preclude moisture condensation buildup on the Tug outer shell during propellant loading and final terminal countdown. Dew point higher than -76F significantly increases required purge gas flow rate.

*Reference JSC 07700

Table 5-2. Interface Study Proposed Orbiter Accommodations

Ident	Title	Effect on Orbiter Accommodations	Interface Area Technical Discipline
001	GN_2 Purge Requirements	Aft vent provisions	Environmental
002	T-0 Fuel Panel Services	Detail description	Fluid/electrical
003	T-0 Oxidizer Panel Services	Detail description	Fluid/electrical
004	Keel FTG Rotation Mod	New deployment requirement	Structural
005	RMS End Effector	Detail requirements	Mechanical
006	RMS Control Requirements	Detail description	Mechanical
007	Orbiter C&W Requirements	P/L use	Safety
008	Prop Orientation Requirements	Settling thrust	Fluids
009	Fwd BHD Services	Detail description	Electrical
010	Aft BHD Services	Detail description	Fluid/electrical
011	Vent & Dump Requirements	Exhaust Provision	Fluids
012	Data Bus Access	Expanded P/L use	Avionics
013	Expanded C&W Cap	More capability	Avionics
014	Expanded PSP Cap	Expanded P/L use	Avionics
015	1307 Panel Relocate	Grnd OPS requirement	Fluid/electrical
016	Fwd Umbilical Panel	Flexible services	Fluids
017	Command Cap Requirements	Expanded P/L use	Avionics
018	TLM Input Requirements No. 1	Detail description	Avionics
019	Struct Support Clarif	Clarification	Structural
020	New Bridge Beam	New requirement	Structural
021	TLM Input Requirements No. 2	Detail description	Avionics
022	Crew Cabin I/F	Expanded P/L use	Avionics

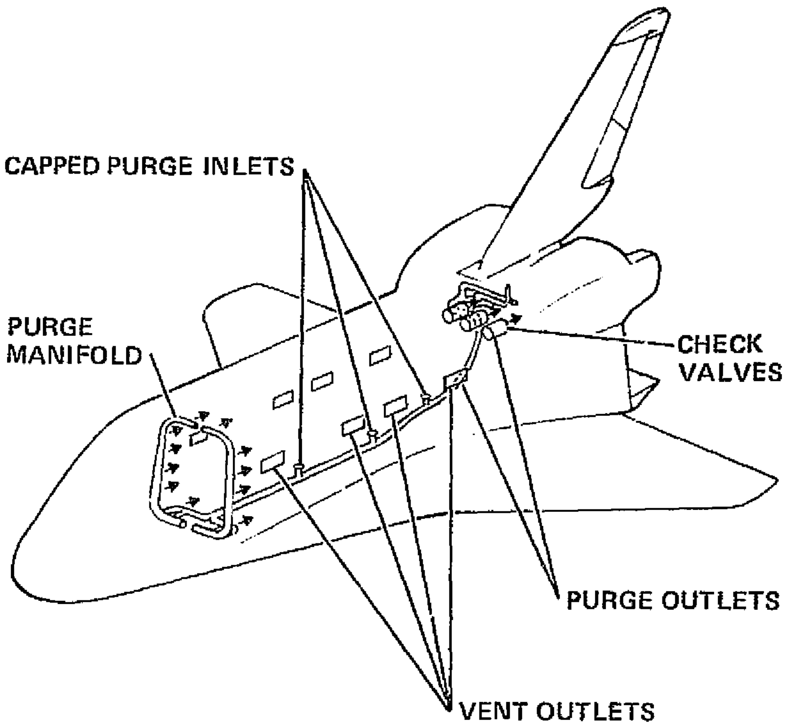

Figure 5-1. Orbiter Prelaunch Conditioning Provisions

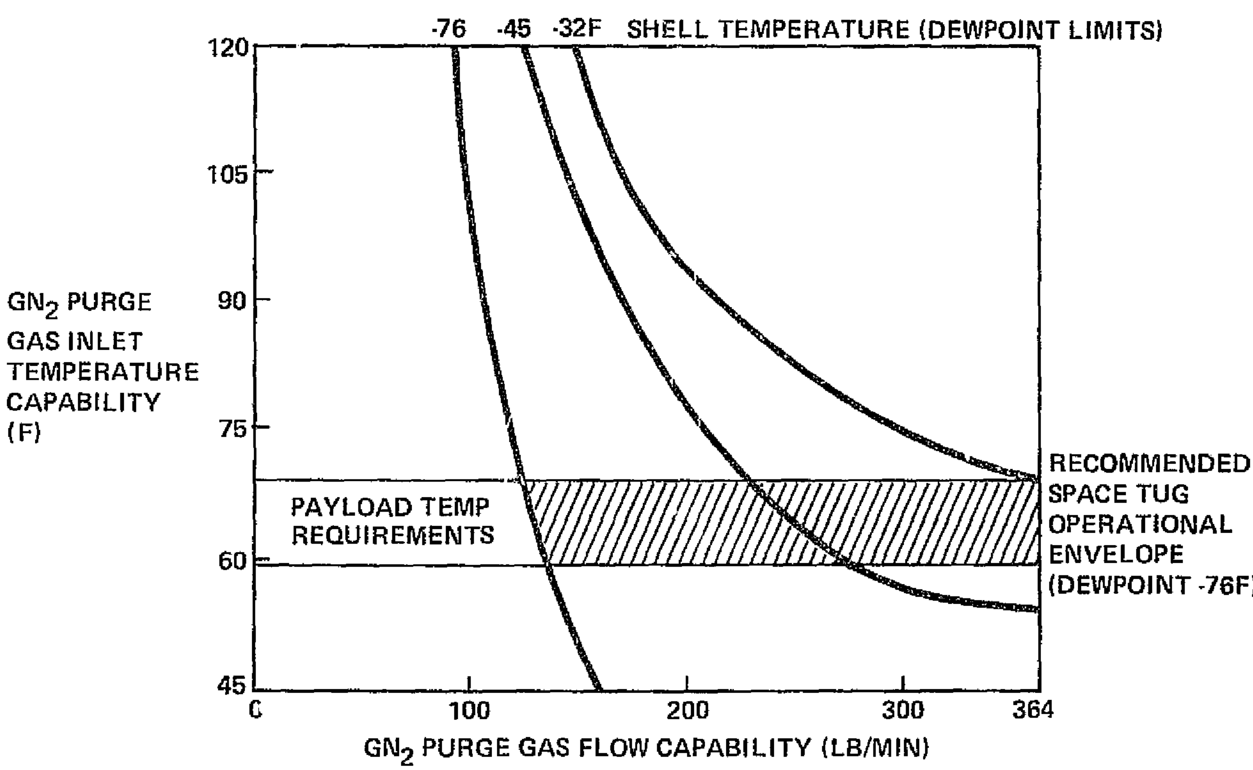

Figure 5-2. Tug Plus Payload Purge Requirements

IMPACT DESCRIPTION:

Ground operations and associated software for propellant loading to incorporate programmed biasing or closure of the 3 LH and 3 RH forward payload bay vents during propellant loading and terminal countdown.

Payloads will be maintained within specified surface temperature limits based upon currently available SSPD data.

IMPACT OF NONINCORPORATION:

If total flow of approximately 115 lb/min minimum from the aft bulkhead vents and 25 lb/min minimum from the X_0 station 1128 vents at an inlet temperature of 59F to 69F GN_2 is not routed past both spacecraft and Tug, there is a possibility of condensation buildup and freezing on the Tug surface which could later outgas during Shuttle orbital flight and adversely impact sensitive spacecraft sensors. In addition, spacecraft surface temperature lower limits will be maintained within an envelope which meets 100 percent of the requirements currently specified in the SSPD data.

5.2 GDC 002 R2, T-0 FUEL PANEL SERVICES

CHANGE TITLE:

Payload/GSE Fluid and Electrical Service at the Orbiter T-0 Launch Umbilical Fuel Panel 521

DESCRIPTION OF CHANGE:

Page 5-6, Table 5.2.* Size fluid and electrical services of the T-0 launch umbilical fuel panel to accommodate as a minimum, the fluid and electrical services indicated in attached Table 5-3 (electrical) and Table 5-4 (fluids).

Page 5-15, Figure 5-6.* (See Figure 5-3.)

Note: Blow-up of P/L portions of this panel required to show true size, extent and locations of payload interface.

REASON FOR CHANGE:

Electrical Services: Services indicated in Table 5-3 are required to accommodate the Tug vehicle with multiple (three) payloads during prelaunch operations.

*Reference JSC 07700

Table 5-3. Payload/GSE Electrical Services at the T-0 Launch

Cargo	Function	Wire Type	No. of Wires	No. of Pins
Tug	Data Links	TSP	3	9
Tug	Data Links	COAX	1	1
Spacecraft	Safety Control and Monitor	TSP TP	8* 12	24 24

*A total of 15 TSP and 24 TP cables are required by Tug payloads. These numbers were rounded off and split between both T-0 umbilical panels.

Fluid Services

Deletion - None. Three services identified in Table 5.2, Page 5-6** are not required for Tug or its currently identified payloads. They may be required, however, for other Orbiter payloads. These three fluid services are:

1. GH_2 relief line
2. GH_2 accumulator fill line
3. Cold helium fill

Additions

1. Helium Purge/Vent - required to vent purges of LCM (leakage containment membrane) disconnect panels, and all vented seals.

Changes

1. LH_2 Fill, Drain, and Dump - increased diameter from 3.0 to 5.0 inches. Larger line required for RTLS abort dump (new requirement).

2. GH_2 Vent - increased idameter from 2.0 to 3.0 inches. Larger line required to meet pressure drop requirements for GH_2 boiloff.

3. Revise appropriate drawings in Appendix C.**

**Reference JSC 07700

Table 5-4. Payload/GSE Fluid Services at the T-0 Launch Umbilical Fuel Panel 521 (Left Side)

Fluid	Function	Line Code	Line Size Diameter		Design Flow Rate		Design Press		Design Temp.		Remarks
			In.	(mm)	Ft/Sec	(M/S	Psi	(Pa)	°F	(°C)	
LH_2	Fill, Drain & Dump	521-3	5.0	127.0	42.0	12.8	20.0	13.8	0.423	0.253	Vac
GH_2	Vent	521-4	3.0	76.2	110.0	33.5	14.7	10.1	70	21	Jacketed
Helium	Purge/Vent	TBD	0.73	20.32	148.0	45.0	14.7	10.1	70	21	
GH_2	Relief	TBD	2.5	63.5							NTR
GH_2	Accum Fill	521-5	0.5	12.7							NTR
Cold He	Fill	521-23	0.5	12.7							NTR

NTR - Not a Tug or Tug Payload Requirement

LOCATING NO.	FUNCTIONAL OPERATION
521-3	P/L LH_2 FILL, DRAIN & DUMP
521-4	P/L LH_2 TANK VENT
TBD	HELIUM PURGE/VENT
521-23	P/L COLD He FILL (NTR)
521-25	T-0 ELECT.
521-5	GH_2 ACCUM FILL (NTR)
TBD	RELIEF (NTR)

NTR - NOT A TUG OR TUG PAYLOAD REQUIREMENT

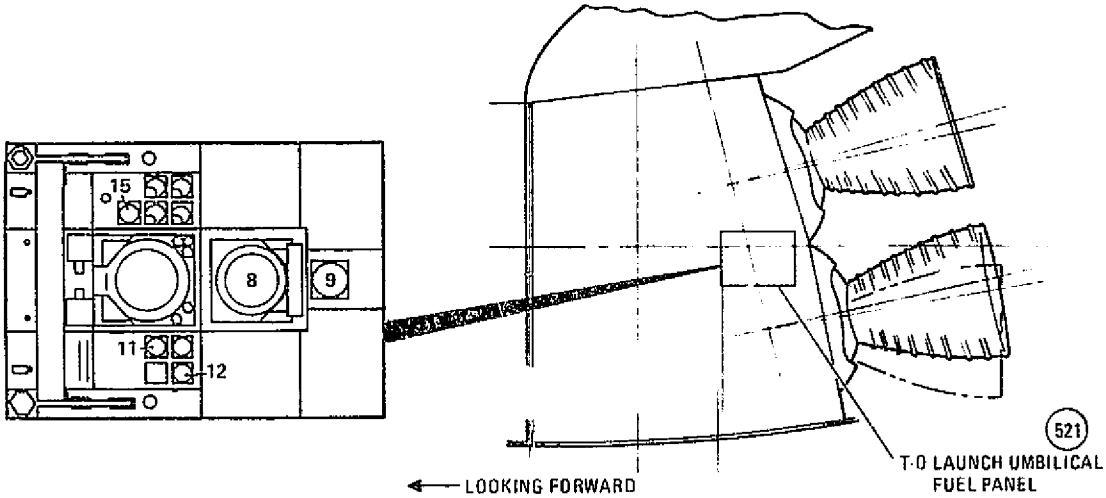

Figure 5-3. Payload/GSE Fluid and Electrical Services (Panel 521)

Explanation

Three fluid services previously included in the T-0 fuel panel are no longer supported by Tug requirements. Tug support has been withdrawn because:

GH_2 Relief Line — All Tug GH_2 vent or relief GSE functions are manifolded into one duct within the Tug. Tug in-flight GH_2 vent/relief functions do use another Orbiter vent outlet not located in the T-0 Orbiter umbilical panel.

GH_2 Accumulator Fill Line — Previously, the space Tug had proposed using an integrated H_2/O_2 APS system which resulted in this service requirement. This APS system has been discarded in favor of one using monopropellant hydrazine. Proposals have been made to convert this service line requirement to a LH_2 fuel cell fill line. The current recommended Tug concept, however, uses an integrated lightweight fuel cell which draws reactants from the main tank propellants, also deleting this potential requirement.

Cold Helium Fill — The previous Space Tug pressurization system stored gaseous helium in a bottle located within the LH_2 propellant tank. Prelaunch bottle fill was accomplished with LH_2 temperature cold He gas after propellant tanking. The current recommended Tug concept has only ambient helium storage.

Helium Purge/Vent -- These service lines cannot be integrated with their respective propellant vent lines because back pressure during venting will generally be higher than the design differential pressure (0.1 psi Δp) of the leakage containment membrane with which they are manifolded.

IMPACT DESCRIPTION:

Revise Orbiter interface panel 521 to fully accommodate Tug requirements.

IMPACT OF NONINCORPORATION:

Nonincorporation will continue to leave this payload/Orbiter GSE interface undefined, thus impacting Orbiter payload design activities.

5.3 GDC 003 R2, T-0 OXIDIZER PANEL SERVICES

CHANGE TITLE:

Payload/GSE Fluid and Electrical Services at the Orbiter T-0 Launch Umbilical Oxidizer Panel 531

DESCRIPTION OF CHANGE:

Page 5-7, Table 5.3,* Size the fluid and electrical service of the T-0 launch umbilical oxidizer panel to accommodate, as a minimum, the fluid and electrical services indicated in Table 5-5 (electrical) and Table 5-6 (fluids).

Page 5-16, Figure 5-7.* See Figure 5-4.

Note: Blow-up of P/L portions of this panel required to show true size, extent, and locations of payload interface.

Changes:

1. LO_2 fill, drain, and dump line diameter - reduced diameter required from 5.0 to 4.0 inches. Latest analysis indicates 4.0 inches diameter adequate.

2. Ambient helium fill - reduced line diameter required from 0.5 to 0.375 inches.

3. Revise appropriate drawings in Appendix C.*

*Reference JSC 00700

Table 5-5. Payload/GSE Electrical Services at the T-0 Launch Umbilical Oxidizer Panel 531 (Right Side)

Cargo	Function	Wire Type	No. of Wires	No. of Pins
Tug	Data Links	TSP	3	9
Tug	Data Links	COAX	1	1
Spacecraft	Safety Control and Monitor	TSP TP	8* 12	24 24

*A total of 15 TSP and 24 TP are required by Tug payloads. These numbers were rounded off and split between both T-0 umbilical panels.

REASON FOR CHANGE:

Electrical Services: service indicated in Table 5-5 are required to accommodate the Tug vehicle with multiple (three) payloads during prelaunch operations.

Fluid Services:

Deletions

None — One service identified in Table 5.3, page 5-7, ** is not required for Tug or its currently identified payloads. It may be required, however, for other Orbiter payloads. This fluid service is

1. GO_2 accumulator fill - no requirement for Tug.

2. The GO_2 vent/relief listed in Table 5.3** is not actually located in the oxidizer T-0 umbilical panel, it is located on the Orbiter adjacent to the panel. Remove this function from the table.

Additions

1.& 2. RTG coolant in and coolant out line - RTG cooling water required up to launch (T-0).

3. Helium purge/vent - required to vent purges of LCM (leakage containment membrane) disconnect panels, and all vented seals.

**Reference JSC 00700

Table 5-6. Payload/GSE Fluid Services at the T-0 Launch Umbilical Oxidizer Panel 531 (Right Side)

Fluid	Function	Line Code	Min. Line Size Dia.		Maximum Flow Rate		Press		Temp.		Remarks
			In.	(mm)	Ft/Sec	(M/S)	psi	N/cm^2	°F	(°C)	
Amb He	Fill	531-9	0.375	9.53	151.0	46.0	3200	2205	70	21	
LO_2	Fill, Drain & Dump	531-6	4.0	101.6	23.4	7.13	30	20.7	-297	-183	
Helium	Purge/Vent	TBD	0.75	19.05	16.8	5.05	14.7	10.1	70	21	
LO_2	Topping	TBD	0.75	19.05	6.8	2.1	30.0	20.7	-297	-183	Vac Jacketed
H_2O	RTG Cooling IN	TBD	0.5	12.7	2.05	0.62	50	34.5	70	21	
H_2O	RTG Cooling OUT	TBD	0.5	12.7	2.05	0.62	50	34.5	120	49	
GN_2	Payload (Spacecraft) Prelaunch Conditioning	TBD	TBD		TBD		TBD		TBD		
GO_2	Accum. Fill	531-7	0.5	12.7							NTR

NTR - Not a Tug or Tug payload requirement

LOCATING NO.	FUNCTIONAL OPERATION
531-6	P/L LO_2 FILL, DRAIN & DUMP
531-9	P/L AMBIENT He FILL
TBD	PL He PURGE/VENT
531-16	T-0 ELECT.
TBD	PL LO_2 TOPPING
TBD	PL RTG COOLANT IN
TBD	PL RTG COOLANT OUT
TBD	GO_2 ACCUM. FILL (NTR)

NTR – NOT A TUG OR TUG PAYLOAD REQUIREMENT

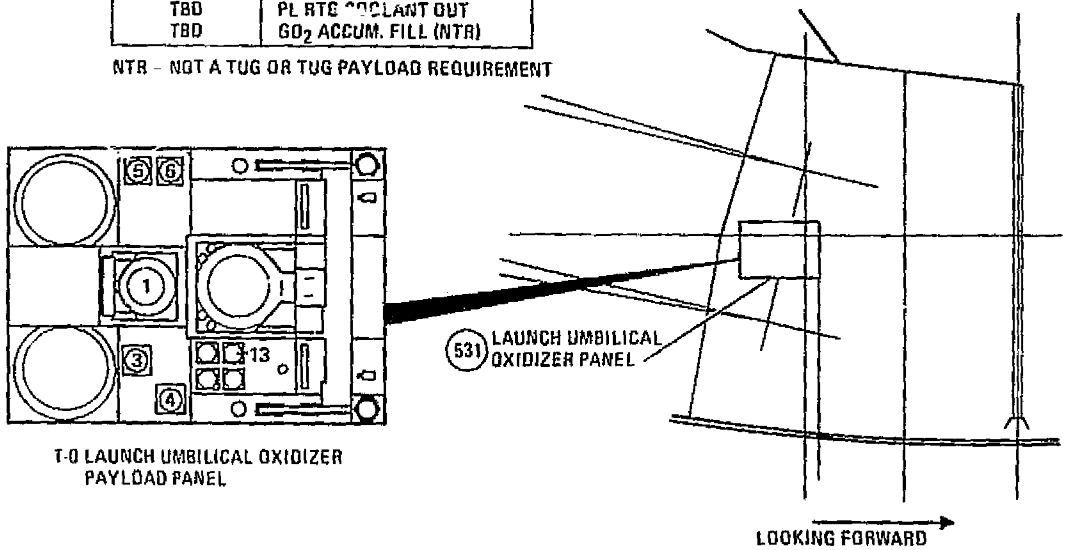

Figure 5-4. Payload/GSE Fluid and Electrical Services (Panel 531)

4. LO_2 topping line - separate small diameter vacuum jacketed line required to meet temperature rise requirements during prelaunch tank replenishing.

5. Add separate line TBD diameter for high quality gas inlet for spacecraft prelaunch conditioning.

Explanation

One fluid service previously included in the T-0 oxidizer panel is no longer supported by a Tug requirement. Tug support has been withdrawn because:

GO_2 accumulator fill - previously, the space Tug had proposed using an integrated H_2 - O_2 APS system which resulted in this service requirement, this system has been discarded in favor of an APS using monopropellant hydrazine. Proposals have been made to convert this service line requirement to a LO_2 fuel cell fill line. The current recommended Tug concept, however, uses an integrated lightweight fuel which draws reactants from the main tank propellants, also deleting this potential requirement.

Helium purge/vent - these service lines cannot be integrated with their respective propellant vent lines because back pressure during venting will generally be higher

than the design differential pressure (0.1 psi ΔP) of the leakage containment membrane with which they are manifolded.

IMPACT DESCRIPTION:

Revise Orbiter interface panel 531 to fully accommodate Tug plus payload requirements.

IMPACT OF NONINCORPORATION:

Nonincorporation will continue to leave this payload/Orbiter/GSE interface undefined, thus impacting Orbiter/payload design activities.

5.4 GDC 004 R1, KEEL FITTING ROTATION MOD

CHANGE TITLE:

Space Tug Attachment: Provision for Rotational Deployment

DESCRIPTION OF CHANGE:

Revise keel fitting installations X_o 1249, X_o 1181, X_o 1128, and X_o 951 to accommodate Tug rotational deployment about an axis through X_o 1246, Z_o 414.

REASON FOR CHANGE:

Rotational deployment berthing of Tug about X_o 1246, Z_o 414 results in substantial horizontal motion of the Tug Y-support during keel fitting entry/exit.

The present keel fitting concepts, shown on both Page C-14 and Rockwell layout VL73-004167,* do not permit horizontal entry/exit of the Tug Y-support.

Revised fitting installations incorporating alignment provisions, similar to those shown in the concept sketches, are required. See Figures 5-5 and 5-6.

IMPACT DESCRIPTION:

Design change plus probable minor weight increase in keel fittings.

IMPACT OF NONINCORPORATION:

Tug/Orbiter interference precluding rotational Tug deployment/berthing.

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*Reference JSC 07700

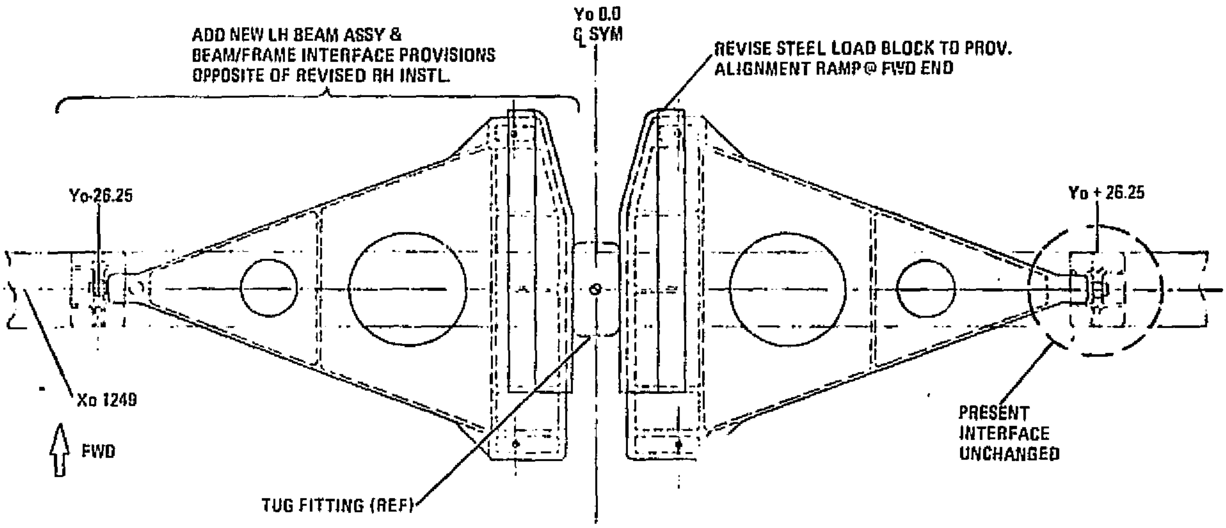

Figure 5-5. Orbiter Bridge Fitting Concept — Rotational Deployment with Y Fitting at X_o 1249

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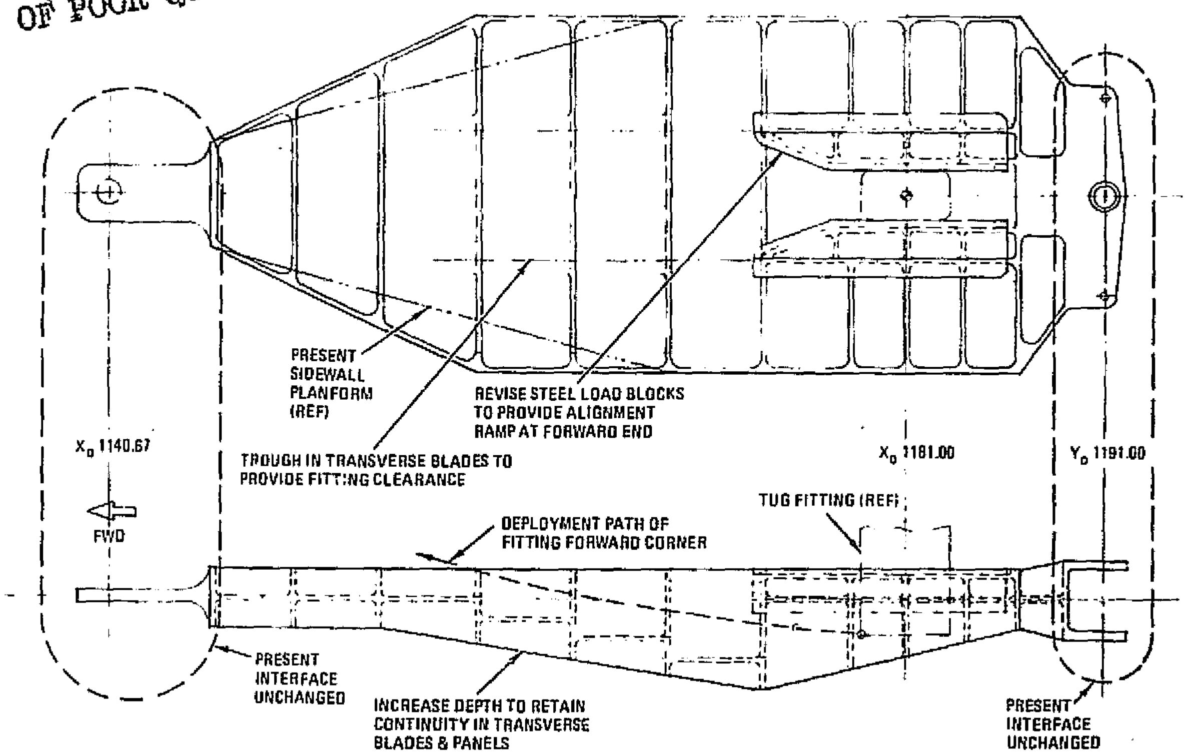

Figure 5-6. Orbiter Bridge Fitting Concept — Rotational Deployment with Y Fitting at X_o 1181

5.5 GDC 005, RMS END EFFECTOR

CHANGE TITLE:

Remote Manipulator System End Effector Requirements

DESCRIPTION OF CHANGE:

Add to Section 8.0:*

The RMS terminal device/end effector will have sufficient load capability to accomplish deployment and retrieval of a 65,000 lb payload, and the dexterity necessary for servicing and equipment backup functions. For special-purpose functions, on-orbit end effector exchange and stowage will be provided. The end effector will incorporate a proximity switch to activate a grasp-upon-contact device.

REASON FOR CHANGE:

The RMS value will be enhanced by providing flexibility of function beyond that which is mission prescheduled. A specific backup function for Tug is to disconnect a failed redundant deployment actuator to allow mission completion; a wrenching or grasping function is anticipated. For Tug deployment/retrieval, a probe type end effector is considered optimum therefore requiring interchange capability. A switch to signal contact will prevent payload push away during retrieval.

IMPACT DESCRIPTION:

Provide interchangeable end effectors.

IMPACT OF NONINCORPORATION:

Use of RMS will be limited resulting in increased EVA.

5.6 GDC 006 R1, RMS CONTROL REQUIREMENTS

CHANGE TITLE:

Remote Manipulation System Control Requirements

*Reference JSC 07700

DESCRIPTION OF CHANGE:

All new Para. 8.4* as follows:

8.4 RMS CONTROL REQUIREMENTS

The RMS control system will accommodate the basic operational requirements (Ref. Para. 8.1)* through a combination of manual and preprogrammed input devices. Specific control capabilities include:

a. Six D.O.F. position control

b. Velocity control (rate and direction)

c. Orbiter clearance and RMS end of travel control

Input to the RMS control system is through the:

a. RMS operator hand controller

b. CRT keyboard

c. Payload peculiar software

d. Orbiter/RMS standard software

Input device functions will be capable of being coordinated to either a set of geometric axes or to the "on line" video monitor axes.

REASON FOR CHANGE:

RMS use for Tug deployment and retrieval and for backup servicing tasks requires knowledge of the control system capabilities to properly design payload peripheral/ Orbiter interface equipment.

RMS end effector velocity control is required to enable matching the end effector rate of travel to Tug drift relative to the Orbiter for attachment during retrieval. The Orbiter will be positioned below the Tug, aligned for direct mission through the docking port window and stabilized to near zero relative motion. The RMS end effector will then be aligned to the Tug receptacle, as viewed through the RMS located TV monitor, adjusted with the RMS operator hand controller, extended and attached to Tug.

A Tug peculiar program will then be initiated via the CRT keyboard to reposition the Tug for insertion into the Orbiter cargo bay. Tug position will be verified and fine adjusted through the TV view near the Tug docking attachments. (Anticipated location

*Reference JSC 07700

is either on the longeron at approx. Sta. 1260 or on the Tug deployment adapter). Continuing, the Tug program will move it along a preselected path and rate enabling manual video monitoring and corrective trim adjustments.

For servicing/backup functions the RMS will be manually controlled utilizing both direct vision and TV monitoring. The control will require a six degree of freedom system to align the RMS tools/end effectors for task accomplishment.

The RMS control system requires self check capability to prevent damage by collision of all parts of the system. The small tip force capability of the RMS can produce significant velocities in payloads weighing up to 65,000 lb. Continuous monitoring is therefore necessary to assure that the velocity is limited to values that can be arrested by the RMS tip force prior to any collision. An Orbiter/RMS standard program is needed to oversee this safety critical function.

Explanation

Input Portion of Control Requirement — In addition to understanding what the Orbiter supplied RMS capability is, users must be cognizant of how their specific control requirements can be implemented by the Orbiter system. The broad range of control inputs requested by this change identifies to each potential user the Orbiter RMS control flexibility, which allows him to select the most suitable method of control for his particular application.

IMPACT DESCRIPTION:

Change data needed for design of impacted areas.

IMPACT OF NONINCORPORATION:

N/A

5.7 GDC 007, ORBITER C&W REQUIREMENTS

CHANGE TITLE:

Identification of C&W Requirements and RMS Contingency Operations Capability on Orbiter Supplied Equipment Used by Payloads

*Reference JSC 07700

DESCRIPTION OF CHANGE:

To paragraph 11.2,* add:

11.2.1 Space Tug Requirements. During joint Orbiter Tug operations, the Orbiter must provide visual and audible Caution & Warning indications on the following Orbiter supplied interface devices:

a.	Support latches	OPEN-CLOSED
b.	RMS	STOWED-RETRACT CLEAR
c.	T-0 Umbilical Doors	OPEN-CLOSED
d.	Cargo Bay leak detectors	H_2, O_2, N_2H_4

The Orbiter shall also provide either by RMS capability or through crew EVA, the ability to operate/connect/disconnect the following Orbiter-Tug interface devices:

a.	Support latches	RELEASE-ENGAGE
b.	Station 1307 Umbilical Panels	DISCONNECT

REASON FOR CHANGE:

Capabilities are required to satisfy Safety Requirements stated in MSFC 68M00039-1, Baseline Space Tug System Requirements and Guidelines, dated July 1974. Paragraph 3.2.6.1.2 d states that hazards generated by Tug-Spacecraft/Orbiter interactions shall be identified and mutually resolved or controlled. Paragraph 3.2.6.1.2 s identifies a requirement for Tug jettison (release) while Paragraph t establishes a requirement to provide for emergency manual release of Tug to Orbiter connections. Sub-Paragraph ak establishes a requirement to detect the presence of spilled fluids in the cargo bay. The general requirement for C&W monitors of safety critical functions applies to the identified C&W requirements.

Prior to Tug rotation for deployment; it is necessary to move the RMS from STOWED to RETRACT CLEAR position to clear the Tug rotation envelope and to verify that support latches are OPEN or manually released via RMS/EVA backup.

During abort operations it is essential to verify the T-0 Umbilical panel door position; i.e., for an RTLS abort they must be OPEN to complete propellant dump and for AOA/ATO abort the door must be CLOSED to provide axial thrust for propellant settling during the long duration low-g dump operations. (Refer to GDC Change Request 011)

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*Reference JSC 07700

All Tug fluid tanks are protected by redundant valves or enclosed in containment membranes ducted overboard to reduce the probability of hazardous fluid leakage into the cargo bay. The Orbiter should provide H_2, O_2 and N_2H_4 sensors to detect leakage and provide crew C&W indication.

RMS backup or EVA contingency capability to release support latches and disconnect Station 1307 umbilical panel lines is required to permit deployment or jettison of Tug where necessary to close and secure cargo bay doors to permit Orbiter reentry and landing.

IMPACT DESCRIPTION:

Will ensure adequate C&W indications to crew for joint Tug-Orbiter operations and provide backup capability to accomplish manual release.

IMPACT OF NONINCORPORATION:

Could lead to hazardous conditions without crew knowledge and thus endanger the Orbiter and its flight crew.

5.8 GDC 008, PROPELLANT ORIENTATION REQUIREMENTS

CHANGE TITLE:

Payload Propellant Orientation Requirements for Abort Dump Operations

DESCRIPTION OF CHANGE:

Revise text of Paragraph 12.2.6* to read as follows:

12.2.6 Payload Fluid Dump Provisions

The Orbiter provides for the dumping of the LO_2 and LH_2 of any cryogenic upper stage during the Return-To-Launch-Site (RTLS), Abort-Once-Around (AOA), Abort-To-Orbit (ATO), and Abort-From-Orbit modes. Provisions for the dumping of other payload fluids are TBD. The LO_2 and LH_2 dump is performed under a forward, longitudinal acceleration force which positions the LO_2 and LH_2 in the rear of its tank. The dump lines in the Orbiter interface with the payload at the 1307 inch bulkhead and exit to space via the T-0 umbilicals.

The cryogenic upper stage must provide the interface pressure. It must also provide the dump lines from its tanks to the 1307 bulkhead and all valves, control, etc., needed to carry out safe dump operations under the control of the Orbiter.

*Reference JSC 07700

The dumping operations during the several abort modes are carried out as follows:

a. RTLS - The MPS burn, a minimum of 300 seconds, provides the forward, longitudinal acceleration force for LO_2 and LH_2 orientation in their tanks.

b. AOA - A minimum of 20 seconds of the OMS burn that establishes the once around trajectory provides the forward, longitudinal acceleration force for initial LH_2 and LO_2 orientation. Control is maintained by the RCS. After initiation of dump during OMS burn, dump is continued to near depletion with thrust developed by the dump propellants providing the forward acceleration force for continuous propellant orientation. For the last 50 seconds of dump, four longitudinal aft facing. RCS thrusters are fired to increase longitudinal acceleration and reduce propellant residuals. Total time from initiation to completion of dump is 1100 seconds.

c. ATO - The dump operations will be carried out in the same manner as for AOA except that the return to earth may be delayed to a later revolution. A minimum OMS or RCS burn of 20 seconds is provided for initiation of dump.

d. Abort From Orbit - An abort originating any time after the establishment of the Shuttle initial orbit but before the deployment of the upper stage would initiate the propellant dump by use of an OMS or RCS burn with minimum duration of 20 seconds. The remainder of the dump operations are the same as for AOA.

   Figure TBD shows the abort profiles of the abort modes. Maximum time available for dump is indicated.

REASON FOR CHANGE:

The proposed change clarifies requirements for Tug propellant orientation during abort dump, as follows:

1. RTLS - Minimum MPS burn specified as 300 seconds, was TBD.

2. AOA, ATO, AFO - OMS or RCS operation of 20 seconds specified at dump initiation was TBD. Fifty seconds of RCS operation (4 aft-facing thrusters) specified during completion of dump. This is a new requirement identified in the Space Tug/Orbiter interface compatibility study.

IMPACT DESCRIPTION:

This requirements impacts the Orbiter flight operations and associated software with respect to providing axial thrust during abort dump of Tug propellants.

The requirement impacts the Orbiter design since it is necessary for the Orbiter to include the necessary provisions to insure that the dump propellants provide a forward thrust during any on orbit dumps.

IMPACT OF NONINCORPORATION:

Orbiter operations not compatible with Shuttle requirements.

5.9 GDC 009 R1, FORWARD BULKHEAD SERVICES

CHANGE TITLE:

Payload/GSE Electrical Services at the Orbiter Forward Bulkhead (Station 576) Panel.

DESCRIPTION OF CHANGE:

Para. 12.5, Table 12-5,* size the electrical services of the Orbiter forward bulkhead to accommodate, as a minimum, the electrical services indicated in Table 5-7.

Note: Indicate via an illustration portions of forward bulkhead panel to show true size, extent, and locations of payload interface.

REASON FOR CHANGE:

Electrical services; services indicated in Table 5-7 are required to accommodate the Tug vehicle and multiple (three) payloads during flight operations.

IMPACT DESCRIPTION:

Change JSC 07700, Vol. XIV, Rev. C to reflect required electrical services at the station 576 forward bulkhead panel.

IMPACT OF NONINCORPORATION:

Lack of definition of electrical payload services at station 576 can impair payload and Orbiter design activities.

5.10 GDC 010 R2, AFT BULKHEAD SERVICES

CHANGE TITLE:

Payload/GSE Fluid and Electrical Services at the Orbiter Aft Bulkhead Station 1307

*Reference JSC 07700

Table 5-7. Payload Electrical Services at Forward Bulkhead Station 576

Signal Control and Monitoring							
Interface Location							
Y_o	Z_o	Function	Connector	Wire Type	No. Wires	No. Pins	Cargo
TBD	TBD	Data Link	TBD	TSQ	2	10	Tug
TBD	TBD	Command/ Monitor	TBD	TSP	37	111	Tug
TBD	TBD	Command/ Monitor	TBD	TSP	98	294	Spacecraft
TBD	TBD	Data Link	TBD	COAX	3	3	Spacecraft

DESCRIPTION OF CHANGE:

Para. 12.2.2, Page 12-2 and Table 12.2,* size the fluid and electrical services of the station 1307 aft bulkhead service panel to accommodate, as a minimum, the fluid and electrical services indicated in attached Table 5-8 (electrical) and Table 5-9 (fluids).

Note: Indicate using figure portions of aft bulkhead panel required to show true size, extent, and locations of payload interface.

All payload storable propellant service lines and Tug APS (N_2H_4) will be routed via the IUS storable panels (527/528) on the 1307 bulkhead to their respective disconnect panels (535/536) on the Orbiter firewall.

REASON FOR CHANGE:

Electrical Services: Services indicated in Table 5-8 are required to accommodate the Tug vehicle with multiple (three) payloads during prelaunch operations.

Fluid Services: Services indicated in Table 5-9 are required to accommodate the Tug and its payloads during prelaunch servicing operations.

*Reference JSC 07700

Table 5-8. Electrical Payload Services at Aft Bulkhead Station 1307

Function	Connector	Wire Type	No. Wires	No. Pins	Cargo	Remarks
Data Links	TBD	TSP	6	18	Tug	Interfaces with both T-0 fuel and oxidizer umbilical panels
Data Links	TBD	COAX	2	2	Tug	
Safety Control/ Monitor	TBD	TSP	15	45	Spacecraft	
	TBD	TP	24	48		

Deletions

None — Three services identified in Table 12.2, Page 12-6* are not required for Tug or its currently identified payloads. They may be required, however, for other Orbiter payloads. These fluid services are:

1. LH_2 fuel cell fill and drain
2. LO_2 fuel cell fill and drain
3. Cold He fill

Additions

1 & 2. Helium purge/vents — required to vent purges of propellant tank insulation system LCM (leakage containment membrane), disconnect panels, and all vented seals associated with the LH_2 and LO_2 propellant tanks.

3. LO_2 topping line — separate small diameter vacuum jacketed line required to meet temperature rise require nents during prelaunch tank replenishing.

4, 5 & 6. RTG water coolant and steam vent lines — incorporate in oxidizer panels to provide ground RTG cooling water up to launch, and steam vent capability during ascent and predeployment.

Changes

1. LH_2 Fill, Drain, & Dump — increased diameter from 3.0 to 5.0 inches. Larger line required for RTLS Abort Dump (new requirement).

*Reference JSC 07700

2. GH_2 Vent — increased diameter from 2.0 to 3.0 inches. Larger line required to meet pressure drop requirements for GH_2 boiloff.

3. LO_2 Fill, Drain, & Dump Line Diameter — reduced diameter required from 5.0 to 4.0 inches. Latest analysis indicates 4.0 inches diameter adequate.

4. Ambient Helium Fill — Reduced line diameter required from 0.5 to 0.375 inches.

Explanation

Three fluid services previously included in the station 1307 service panels are no longer supported by Tug requirements. Tug support has been withdrawn because:

LH_2 fuel cell fill & drain - the current recommended Tug concept uses an integrated lightweight fuel cell which draws reactants from the main tank propellants, thus deleting this requirement.

LO_2 fuel cell fill & drain - Same as above.

Cold helium fill - the previous Space Tug pressurization system stored gaseous helium in a bottle located within the LH_2 propellant tank. Prelaunch bottle fill was accomplished with LH_2 temperature cold He gas after propellant tanking. The current recommended Tug concept has only ambient helium storage.

Lines in the station 1307 service panels for both GH_2 vent and GH_2 relief - the vent line is routed through the Orbiter engine compartment to the T-0 launch umbilical fuel panel and is used only for ground functions. The relief line is ducted to some remote Orbiter location (probably the tip of the vertical stabilizer) and is used for all in-flight pressure regulation (relief) of Tug hydrogen propellant(s).

IMPACT DESCRIPTION:

Modifies station 1307 interface panels to accommodate cryogenic Tug payloads.

IMPACT OF NONINCORPORATION:

Nonincorporation will continue to leave this payload/Orbiter/GSE interface undefined, thus impacting Orbiter/Payload design activities.

5.11 GDC 011 R1, VENT & DUMP REQUIREMENTS

CHANGE TITLE:

Cryogenic Upper Stage Inflight Vent and Dump Requirements

Table 5-9. Payload Services at Aft Bulkhead Station 1307

Interface Panel	Fluid	Function	Line Size Diameter		Flow Rate		Press Rate		Temp Rate		Remarks
			in.	(mm)	lb/sec	(kq/sec)	psi	(Newton/ cm^2)	0F	(0C)	
Cryo Propulsive Payload, Fuel	LH_2 Propellant	Fill, Drain & Dump	5.0	(127)	25.0	(11.34)	20.0	(13.8)	-423	(-253)	2 fuel panels on -Y side of lower bulkhead. Panel internal arrangement TBD.
	GH_2	Vent	3.0	(76.2)	0.25	(0.1134)	14.7	(10.1)	70	(21)	
	GH_2	Relief	2.5	(63.5)	0.17	(0.077)	14.7	(10.1)	70	(21)	
	Cold He	Fill	1/2								NTR
	LH_2 Fuel Cell Reactant	Fill & Drain	1/2								NTR
	Helium	Purge/Vent	0.75	(19.05)	0.0083	(0.0038)	14.7	(10.1)	70	(21)	LH_2 Fill & GH_2 vent & relief lines are Vac. jacketed.
Cryo Propulsive Payload, Oxidizer	LO_2 Propellant	Fill, Drain & Dump	4.0	(101.6)	145.0	(65.8)	25.0	(17.2)	-287	(-183)	2 oxidizer panels on +Y side of lower bulkhead panel internal arrangements, TBD.
	GO_2	Vent & Relief	2.0	(50.8)	0.2	(0.09)	14.7	(10.1)	70	(21)	
	Amb. He	Pressurant Charge	0.375	(9.5)	0.26	(0.118)	3200		70	(21)	
	LO_2 Fuel Cell Reactant	Fill & Drain	1/2								NTR
	Helium	Purge/Vent	0.75	(19.05)	0.0005	(0.00013)	14.7	(10.1)	70	(21)	
	LO_2	Topping	0.75	(19.05)	1.5	(0.68)	25.0	(17.2)	-297	(-183)	Vac. jacketed
Cryo Propulsive Payload, Oxidizer	H_2O In	Cooling	0.50	(12.7)	2.05	(0.62)	50.0	(34.5)	70	(21)	RTG cooling with H_2O inlet, outlet & steam vent line. Water lines to 531 T-0 panel; steam vent to TBD on firewall.
	H_2O Out	Water	0.50	(12.7)	2.05	(0.62)	50.0	(34.5)	70	(21)	
	H_2O Steam	Vent	3.0	(76.2)	0.0135	(0.0061)	1.25	(0.86)	110	(43.3)	

NTR: Not a Tug (or Tug payload) requirement

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DESCRIPTION OF CHANGE:

Add Section 12.2.8 to Volume XIV* to reflect Orbiter inflight venting and dump capability provided for cryogenically propelled upper stage vehicles (Tug or IUS).

12.2.8 Cryogenic Upper Stage Inflight Vent & Dump Provisions — Vehicles using cryogenic propellants require overboard vent/dump provisions during Orbiter flight operations. The Orbiter will provide the following interfaces to accommodate these requirements.

GO_2 Relief & GH_2 Relief — Unrestrained relief capability during all Orbiter flight phases. Overboard exhaust ports will be located other than in the T-0 launch umbilical panels.

LH_2 & LO_2 Propellant Tank Insulation Purge Vents (contain GHe plus traces of gaseous propellant) — Unrestrained venting capability during prelaunch, launch, ascent, and pre-Tug-deployment Orbiter operations. Overboard exhaust ports may be located in the T-0 launch umbilical panels if the above requirement is satisfied.

LH_2 & LO_2 Dump — Overboard dump capability during any Shuttle abort mode at altitudes above that of RTLS Abort SSME burnout, for the appropriate dump duration identified in Section 12.2.6* (Ref. GDC Change Request 008). Dump ports may be located in the T-0 panels.

REASON FOR CHANGE:

The Orbiter, as presently configured, closes the T-0 umbilical panel doors at launch and only reopens them during abort. All fluid lines located within these panels are essentially sealed when the umbilical doors are closed, thus preventing vent or dump during most of the Orbiter flight. Space Tug cryogenic propellants, LH_2 & LO_2, continually boil-off during the mission, requiring an unrestrained vent capability to preclude overpressurization of the Tug propellant tanks. Thus, these vent exits should be located outside of T-0 launch umbilical panels.

The Space Tug must dump LO_2 propellant prior to Orbiter glide return for landing to provide an acceptable Orbiter c.g. position. It is equally desirable to dump LH_2 (at altitudes exceeding 200,000 ft) to minimize post landing safety hazards. To accomplish this, external Orbiter dump outlets are required for all Shuttle abort modes.

The Space Tug propellant tanks are surrounded by a leakage containment membrane and multilayer insulation system, both of which are helium purged. The exhaust from the leakage containment membrane may contain small quantities of gaseous propellant

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*Reference JSC 07700

leakage which must be vented overboard. During Orbiter launch ascent, the volume enclosed by the leakage containment membrane must be continually vented to prevent overpressurization of the membrane. On-orbit, venting should be continued prior to deployment to prevent possible degradation of the propellant tank insulation systems.

IMPACT DESCRIPTION:

Flight operatons and associated software must take into account Tug propellant venting, leakage containment membrane purge exhaust and propellant abort dump requirements. Signals to open the T-0 umbilical panel doors or through door penetrations. Orbiter balance, stability and weight during reentry and landing require dumping all Tug LO_2 during abort mission terminations. Post-abort landing operations are simplified if LH_2 has been dumped during flight since LH_2 drain and vent operations are eliminated.

IMPACT OF NONINCORPORATION:

Orbiter will not be operationally capable of transporting cryogenic upper stage vehicles in its payload bay.

5.12 GDC 012, DATA BUS ACCESS

CHANGE TITLE:

Payload Access to Orbiter Data Bus

DESCRIPTION OF CHANGE:

In addition to payload MDM capability, provide payload access to Orbiter data bus system and describe its interface and operating requirements in JSC 07700, Vol. XIV, Rev. C., Section 14. This capability should be redundant in design and payload interfacing units should be required to interface with these data bus ports using the standard Orbiter multiplexer interface adapter (MIA) units (NAR SPEC MC615-0010). (See Figure 5-7.)

REASON FOR CHANGE:

Availability of this interface capability will allow certain Orbiter payloads (Tug/IUS) to achieve a significant reduction in size and complexity of payload/Orbiter interface.

IMPACT DESCRIPTION:

Incorporate capability for payloads to have access to Orbiter data bus.

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*Reference JSC 07700

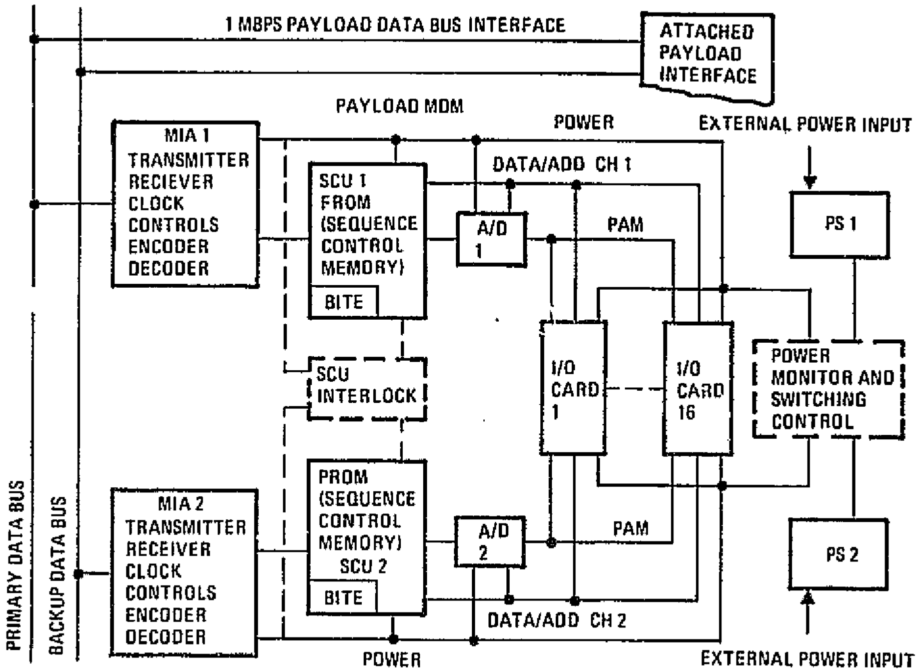

Figure 5-7. Payload Access to Orbiter Data Bus

IMPACT OF NONINCORPORATION:

Nonincorporation will cause, for certain Orbiter payloads, an increased payload/ Orbiter interface and additional interface control logic.

5.13 GDC 013(1), EXPANDED C&W CAPABILITY

CHANGE TITLE:

Orbiter Payload Caution & Warning Capability

DESCRIPTION OF CHANGE:

Change Section 14.1.7,* Caution & Warning to increase the input and annunciator capability of payload caution & warning electronics unit and associated annunciator electronics to accept as a minimum 120 payload C&W input signals and provide a minimum of 40 annunciators.

(1) Subsequent reductions in payload requirements resulted in withdrawal of this change request.
*Reference JSC 07700

REASON FOR CHANGE:

Preliminary Tug and Tug payload data indicates that the current capability for these units (50 inputs and 25 annunciators) is insufficient, with 16 inputs and 12 annunciators being required by Tug and an additional 80 inputs and TBD annunciators being required by Tug multiple payloads (single Tug payloads require up to 60 C&W inputs).

IMPACT DESCRIPTION:

Provide necessary equipment to yield increased payload caution & warning capability in Orbiter crew compartment.

IMPACT OF NONINCORPORATION:

Orbiter will not have the capability to provide sufficient caution and warning for Tug plus multiple payloads.

5.14 GDC 014, EXPANDED PSP CAPABILITIES

CHANGE TITLE:

Orbiter Payload Signal Processor Capability Expansion

DESCRIPTION OF CHANGE:

Change Section 14.2.2* Payload Signal Processor such that:

1. This unit will simultaneously accept multiple telemetry inputs (up to four) from attached payloads.

2. This unit will provide multiple command outputs (up to four) to attached payloads. These output channels should be configured to incorporate dual redundancy for payloads requiring redundant channels.

REASON FOR CHANGE:

The first change noted above will allow payloads to incorporate redundancy in their downlink data without incorporating the extra hardware/software required to interface via the payload data interleaver unit.

The second change noted above will eliminate a simplex communication link with attached payloads and thus provide a completely redundant system.

*Reference JSC 07700

IMPACT DESCRIPTION:

Requires revision of Orbiter payload signal processor to provide increased capability.

IMPACT OF NONINCORPORATION:

Nonincorporation of first change causes size and complexity of payload/Orbiter downlink interface for certain payloads to remain high. Nonincorporation of second change potentially decreases Orbiter/Payload command link reliability.

5.15 GDC 015 R1(1), 1307 PANEL RELOCATION

CHANGE TITLE:

Relocate Bulkhead (Station 1307) Payload Fuel Panel 519 and Payload Oxidizer Panel 584

DESCRIPTION OF CHANGE:

12.2.2 Aft Bulkhead, Station X_o 1307*

No change to paragraph; but modify referenced Drawing VL 70-005126 in Appendix C.*

Appendix C, Drawing VL 70-005126, Sheet 1, Part 2, p. C-39.*

Modify as indicated in attached Figure 5-8. Relocate Payload Fuel Panel (519) and Payload Oxidizer Panel (584) to Z_o 440.

Drawing VL 70-005126, Sheet 2, Part 1, p. C-37.* Revise Z_o 360.62 to read Z_o 440.00.

REASON FOR CHANGE:

Ground operations functions require physical access to inter-bay service panels to accomplish and verify proper connection of fluid and electrical umbilicals during Tug installation operations. The reference payload accommodations documentation shows locations for these various service panels which would preclude the capability of physically observing or reaching these panels. Therefore, it is recommended that the panels be relocated as indicated on Figure 5-8. Further, this change would enable performance of both bubble or sniff type of leak checking if they become necessary.

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(1) This change was requested by the Ground Operations Study, MMC contract NAS 8-31011.

*Reference JSC 07700

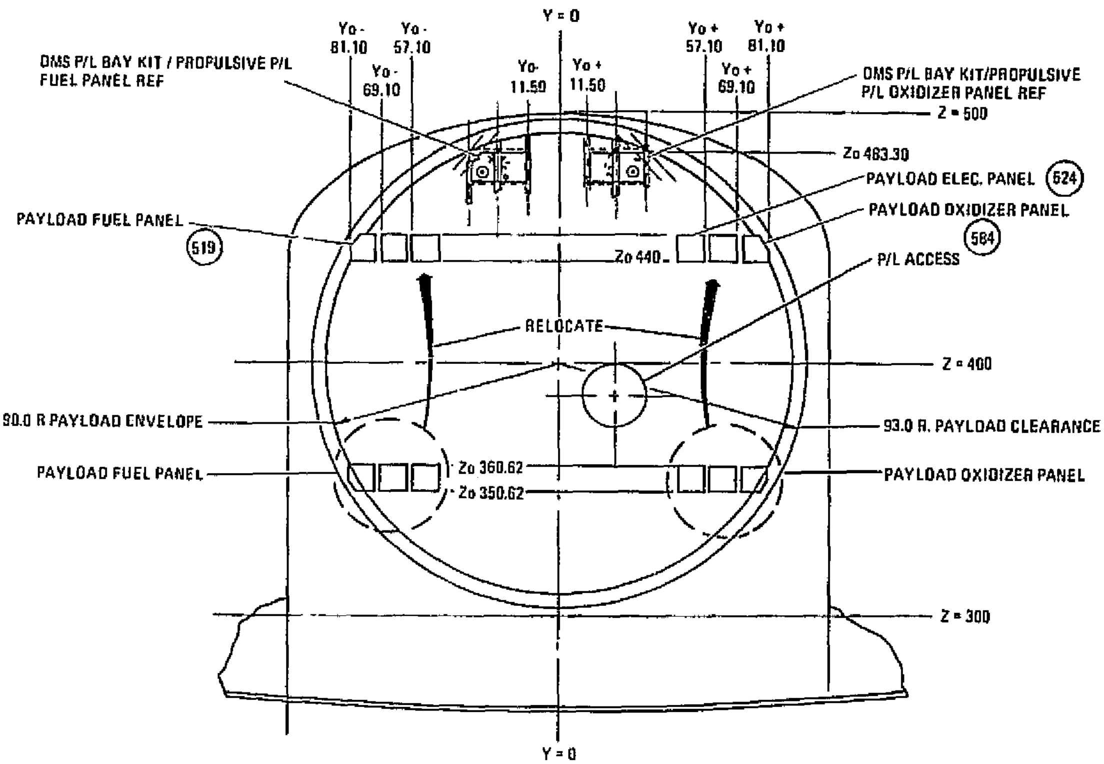

Figure 5-8. Relocation of 1307 Payload Service Panel

IMPACT DESCRIPTION:

Incorporation of this change may require changes in the Orbiter Aft Bulkhead Station X_0 1307) line rerouting and hardware relocation changes in the Orbiter engine compartment.

IMPACT OF NONINCORPORATION:

While access requirements are considered to be minimal to marginal for physically accomplishing and verifying proper connections in the aft-bay area, it allows little room for contingency growth or equipment relocation. Special GSE requirements with constrained access procedures and resulting limitation on ground crews physical size could result from current configuration.

RECOMMENDATION/REMARKS

Fully investigate relative cost/weight of flight hardware change for relocation of aft bulkhead (Station X_0 1307) service panels versus acceptability of minimal access working envelope for attaching/disconnecting and verifying Tug to Orbiter fluid and electrical umbilicals.

5.16 GDC 016A, FORWARD UMBILICAL PANEL

CHANGE TITLE:

Provide Raceway/Mounting Accommodation for a Forward Payload Umbilical Panel

DESCRIPTION OF CHANGE:

Add 12.2.9 Payload Bay Umbilical Panels*

Many Space Shuttle missions have multiple payloads including on-orbit payload exchange. To standardize Orbiter interfaces while maintaining desired payload mix flexibility, provisions for umbilical panels are located at multiple fuselage stations Y_0 = -30 (75 cm) and X_0 -9.8 in. (25 cm) from each of the 13 primary attachment locations of Figure 7-4.*

The panels will enable disconnect of payload fluid and electrical services for deployment and reconnect following retrieval. Only the panels required for a particular mission will be installed. The panels, with tubing and hardness necessary for connection to the service panels specified in 12.2.6* shall be chargeable as payload weight.

REASON FOR CHANGE:

Incorporation of this capability provides considerable operational flexibility for both Tug and non-Tug payloads. It affords standard locations with a capability to incorporate payload peculiar panels for special services such as RTG cooling lines, cryogen service lines, special conditioning ducts and bi-propellant service lines. For Tug payloads these special services can be routed to a standard location, thence through Tug and Tug/spacecraft adapter peculiar interfaces to the spacecraft. It would permit satisfying limited use requirements without penalizing Tug design by carrying special lines, etc., on all flights.

Non-Tug payloads which must be mounted forward in the cargo bay could also utilize these umbilical disconnects. Proposed configuration and mounting locations are shown in Figure 5-9.

Thus, operational flexibility and Orbiter/spacecraft interface commonality and simplicity are the key considerations to support this change.

*Reference JSC 07700

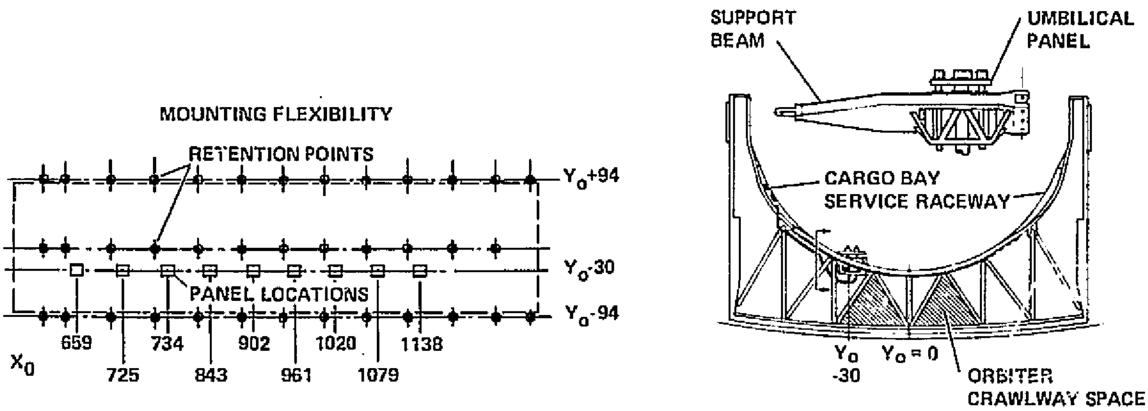

Figure 5-9. Typical Panel Configuration and Suggested Mounting Locations

IMPACT DESCRIPTION:

Minor change in Orbiter/payload service interface accommodation will yield major dividents in operational flexibility.

IMPACT OF NONINCORPORATION:

Orbiter capability to provide required services to both Tug and non-Tug payloads will be impaired and unnecessarily complicated. Conceivably most non-Tug payloads can be mounted at several X_0 positions depending on mission. If standardized umbilicals are not provided, each payload may require several different umbilical designs with the resulting Orbiter changes.

5.17 GDC 017, COMMAND CAPABILITY REQUIREMENTS

CHANGE TITLE:

Orbiter/Payload Command Capability Requirements

DESCRIPTION OF CHANGE:

Modify JSC 07700, Section 14.2, Payload Signal Processor (PSP), to provide capability to: a) Command attached Orbiter payloads via redundant PSP units or output channels, b) Command attached and detached payloads directly at a 2 kbps information rate instead of the proposed 8 kbps encoded data rate.

*Reference JSC 07700

REASON FOR CHANGE:

This change will eliminate a simplex communication link between the Orbiter and attached payloads, and would allow the dual redundant Tug avionics system to interface with the otherwise redundant Orbiter command avionics. Thus, a Tug/Orbiter communication interface reliability improvement should result and Orbiter/payload interface concepts would be consistent with the redundancy implementation concepts used throughout the Orbiter avionics. The second part of this change will eliminate unnecessary payload hardware/software required to synchronize, decode and extract the 2 kbps of actual command data from the 8 kbps of encoded data presently transmitted by the Orbiter's PSP.

IMPACT DESCRIPTION:

Requires revision to Orbiter payload signal processor design.

IMPACT OF NONINCORPORATION:

Nonincorporation causes a potential decrease in Tug/Orbiter reliability and causes payloads an additional burden by requiring implementation of additional hardware/software (possibly nonstandard) with few payload benefits.

5.18 GDC 018 R1, TLM INPUT REQUIREMENTS NO. 1

CHANGE TITLE:

Orbiter/Payload Telemetry Input Requirements Modification 1

DESCRIPTION OF CHANGE:

Modify JSC 07700, Section 14.2.1 and 14.2.2 (Payload Data Interleaver and Payload Signal Processor) to permit multiple and redundant telemetry from attached payloads to be input via the payload signal processor (PSP). This change would also include modification of the PSP/PDI interface such that telemetry data would be transmitted directly from the PSP to the Orbiter's Master PCM units (in a redundant manner).

REASON FOR CHANGE:

The present PSP/PDI configuration is undesirable because a single point failure mode associated with the PDIs simplex output logic to the redundant Orbiter Master PCM units precludes transmission of payload telemetry data to the Orbiter in a true redundant manner. Refer to Figure 5-10.

IMPACT DESCRIPTION:

Requires revision to Orbiter payload signal processor to provide desired capability.

IMPACT OF NONINCORPORATION:

Nonincorporation results in lower Orbiter/payload telemetry link reliability due to present PDI single point failure mode.

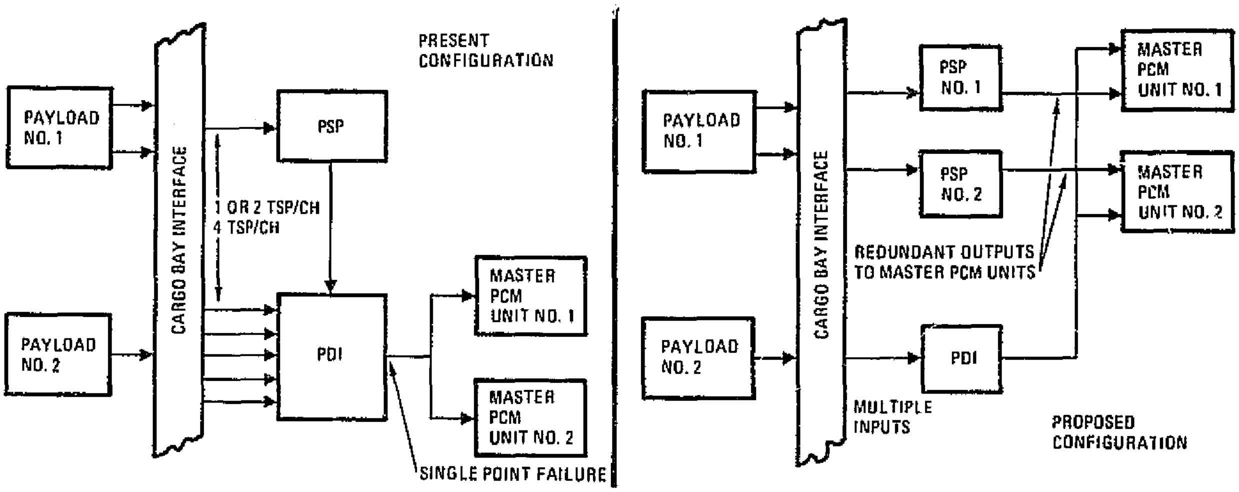

Figure 5-10. Proposed PDI and PSP Modification

5.19 GDC 019, STRUCTURAL SUPPORT CLARIFICATION

CHANGE TITLE:

Space Tug Attachment: Clarification of Orbiter Capability and Design Accelerations

DESCRIPTION OF CHANGE:

1. Clarify definition of Orbiter support capability

   A. Revise Figure 7-7* (and associated text in Para. 7.4)* to limit its applicability to accumulated X-load in the longerons not X-direction payload support reactions applied to the longerons.

   B. Delete Figure 7-9* and the associated text in Para. 7.4.*

*Reference JSC 07700

C. Amend Para. 7.4* and clarify footnotes in the appropriate figures to define the Orbiter support reaction capability for crash (ultimate) loads.

D. Revise Figures 7-8* and 7-10* (and the associated text in Para. 7.4*) to limit the load applied to adjacent bridge fittings to avoid overloading the Orbiter support frame common to both fittings.

2. Revise existing Tables 7-6* and 7-7* plus the associated text in Para. 7.5* to define the reference point at which the angular accelerations act.

REASON FOR CHANGE:

1A. Per Para. 7.3,* X-direction payload support reactions are permitted only at "Primary" support fittings which react Z-direction loads as well. Therefore the permissible X-direction reaction at any primary support location depends on the associated Z-direction reaction. The X/Z interaction envelopes of Figures 7-11* through 7-20* already define these relationships.

B. At "Primary" support fittings the permissible Z-direction reaction depends on the associated X-direction reaction. As noted in Item 1A, Figures 7-11* through 7-20* already define these relationships. At "stabilizing" support fittings the Z-capability can also apparently be obtained from Figures 7-11* through 7-20* by setting X equal to 0. The present Figure 7-9* also implies that the plus and minus Z-capabilities are equal, which conflicts with Figures 7-11 through 7-20.*

C. Presently, Figures 7-7,* 7-8,* and 7-9* each include a footnote indicating that the maximum values on the chart are critical design loads unless exceeded by crash loads. However no information is given to permit assessment of crash loads vs. Orbiter capability. Is it correct to compute a "pseudo-limit" crash load (either reaction/1.4 or 1.1 × reaction/1.4) and compare that value with the stated capabilities? If so, does this apply for X/Z interaction as well as for Y and stabilizing Z reactions?

D. Adjacent bridge fittings attach to a common frame in the Orbiter mid-fuselage. Simultaneously loading both bridge fittings to their individual capability limits overloads the common frame.

2. Total linear accelerations at the payload CG depend on its distance from the point at which this angular accelerations act (i.e., $a_{total} = a_{linear} + R\alpha$). Coordinates for this point of $X_o = 1120$, $Y_o = 0$, $Z_o = 400$ were obtained from Rockwell and used in all reaction computations to date.

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*Reference JSC 07700

IMPACT DESCRIPTION:

Documentation review/revision only.

IMPACT OF NONINCORPORATION:

1A-D. Misunderstanding of Orbiter structural capability.

2. Inability to properly apply angular accelerations.

RECOMMENDATION/REMARKS

Incorporation of the above eliminates ambiguity in Orbiter structural capability definition and prevents incorrect application of angular accelerations.

5.20 GDC 020[1], NEW BRIDGE BEAM

CHANGE TITLE:

Space Tug Attachment: New Bridge Beam

DESCRIPTION OF CHANGE:

Provide new bridge beam spanning from X_o 1249 to X_o 1303, with primary (latching) trunnion at X_o 1269.6.

REASON FOR CHANGE:

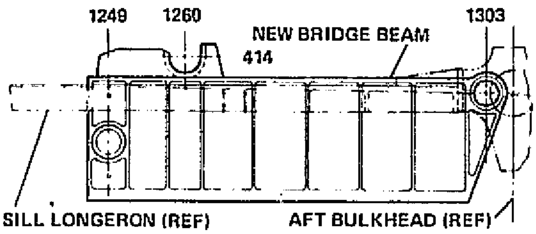
Tug support reactions exceed Orbiter capability using both MSFC and JSC accelerations in all support arrangements employing existing Orbiter provisions. However, all reaction exceedance due to JSC accelerations can be eliminated by using a new bridge beam providing primary X/Z support at Station X_o 1269.6 as shown in Figure 5-11.

The new beam spans from the X_o 1249 mid-fuselage frame to the longeron/bulkhead joint region at X_o 1303. The existing beam/frame Z-load and twist restraint interfaces at X_o 1249 are unchanged. Drag (X) loads are carried aft by the bridge beam and introduced to the Orbiter primary structure at X_o 1303, avoiding drag load application to the sill longerons.

Reactions are tabulated for Tug support configurations 1-1 (four-point) and 2-1 (five-point), with the Y support at X_o 1181, using JSC accelerations. A slight exceedance

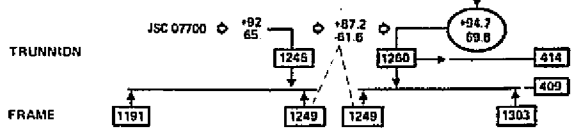
*Reference JSC 07700

• CONCEPT



• SUPPORT REACTIONS

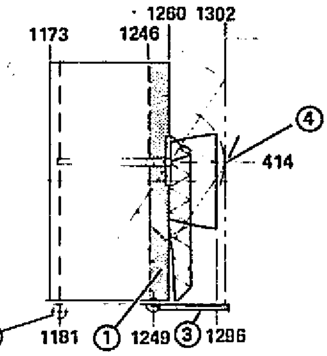
SUPPORT CONFIG	X_1 & X_2 +	X_1 & X_2 −	Y_1 +	Z_1 +	Z_1 −	Z_2 +	Z_2 −	Z_3 +	Z_3 −	Z_4 +	Z_4 −
1 1 (4 POINT)	127.4	65.2	64.6	81.0	81.0	49.1	41.3	55.1	76.0	–	–
2 1 (5 POINT)	127.4	65.2	64.6	61.0	67.1	61.0	67.1	27.5	38.0	27.5	38.0
LOCATION, X_o	1260		1181	1200		1260		951		951	
ORB CAPABIL	TBD	TBD	07	94.7	69.8	94.7	69.8	52.0	67.0	52.0	67.0



• FEATURES

- TRUNNION AT X_o 1249
- USE EXISTING Z I/F AT X_o 1249
- REACT TWIST AT X_o 1249
- AFT X/Z I/F AT X_o 1303

• TUG EFFECTS



(1) INCREASE ADAPTER LENGTH (14 IN.)

(2) RELOCATE Y SUPPORT (X_o 1181)

(3) PROVIDE X REACTION FOR SUPPORT TRUSS –
- REQUIRES BULKHEAD I/F
- USES EXISTING I/F AT X_o 1249

(4) ENGINE NOZZLE REMAINS WITHIN ORBITER ENVELOPE

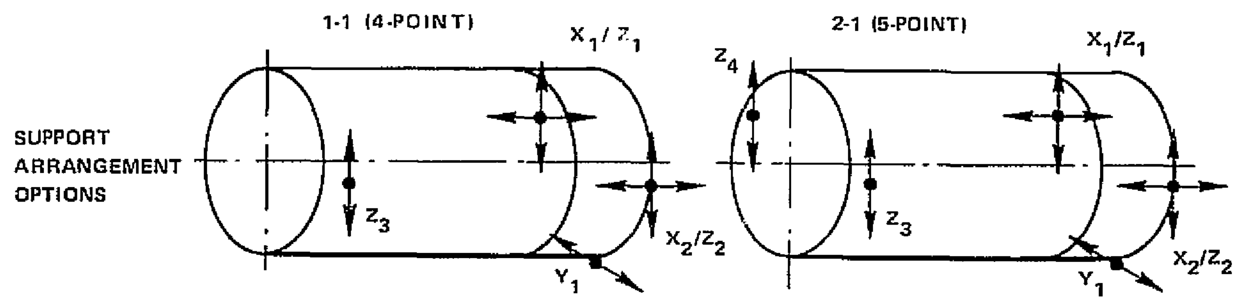
Figure 5-11. Alternative X/Z Orbiter Support

is noted for configuration 1-1, whereas configuration 2-1 is entirely within Orbiter capability. Sufficient Orbiter capability is anticipated at X_o 1303 and the apparent capability for X_o 1269.6 X/Z loading is conservatively derived as shown, by assuming that maximum X and Z reactions occur simultaneously.

For comparison, Table 5-10 and Figure 5-12 present the support reactions (for JSC accelerations only) in both four-point and five-point support configurations using existing Orbiter provisions.

Tug effects associated with the proposed support concept are also shown. The deployment adapter must be lengthened 23.6 inches to align the aft interface frame with the new trunnion location. No Y-support provisions exist at X_o 1269.6, but the existing X_o 1249, X_o 1181, and X_o 1128 locations are still candidates. Of the three, X_o 1181 is preferred since a frame at this station can also react the yaw kick loads in the X-fittings and support the Tug/adapter separation alignment guides. Deletion of the X_o 1249 main Y-support eliminates the X-reaction for the umbilical panel support truss. Consequently, a lightweight link is required which spans from the existing brackets on the X_o 1249 frame to the cargo bay aft bulkhead where a new attachment bracket is required. During rotation with the present Tug engine bell exit plane (X_o 1296) the cargo bay envelope is violated a maximum 1.3 in. by the engine. A

Table 5-10. Support Reaction Comparison for Baseline Tug Using Current Orbiter Provisions



Support Arrangement	Accelerations	Support Reactions: Magnitude/Location/Orbiter Capability										
		X_1 & X_2		Y_1	Z_1		Z_2		Z_3		Z_4	
		+	−	±	+	−	+	−	+	−	+	−
1-1	JSC	150.7	79.4	64.6	79.8	79.8	51.1	42.9	53.1	76.2	-	-
2-1	JSC	150.7	79.4	64.1	57.3	61.4	57.3	26.6	38.1	26.6	26.6	38.1
Location, X_0		1246		1249	1246		1246		951		951	
Orbiter Capability		*	*	56.0	*	*	*	*	52.0	67.0	52.0	67.0
Ref. Fig. No.**		7-20	7-20	7-8	7-20	7-20	7-20	7-20	7-15	7-15	7-15	7-15

Notes:
1. Accelerations per JSC 07700, Vol. XIV, Rev. C, Table 7-6 & MSFC 68M00039-1, Figure 6.**
2. Reactions are those applied to Orbiter by Tug.
3. Sign convention is: +X Aft; +Y Right, Looking Fwd; +Z Up.
4. Orbiter capability per JSC 07700, Vol. XIV, Rev. C
5. * Indicates X/Z interaction; see Figure 2.**

**Reference JSC 07700

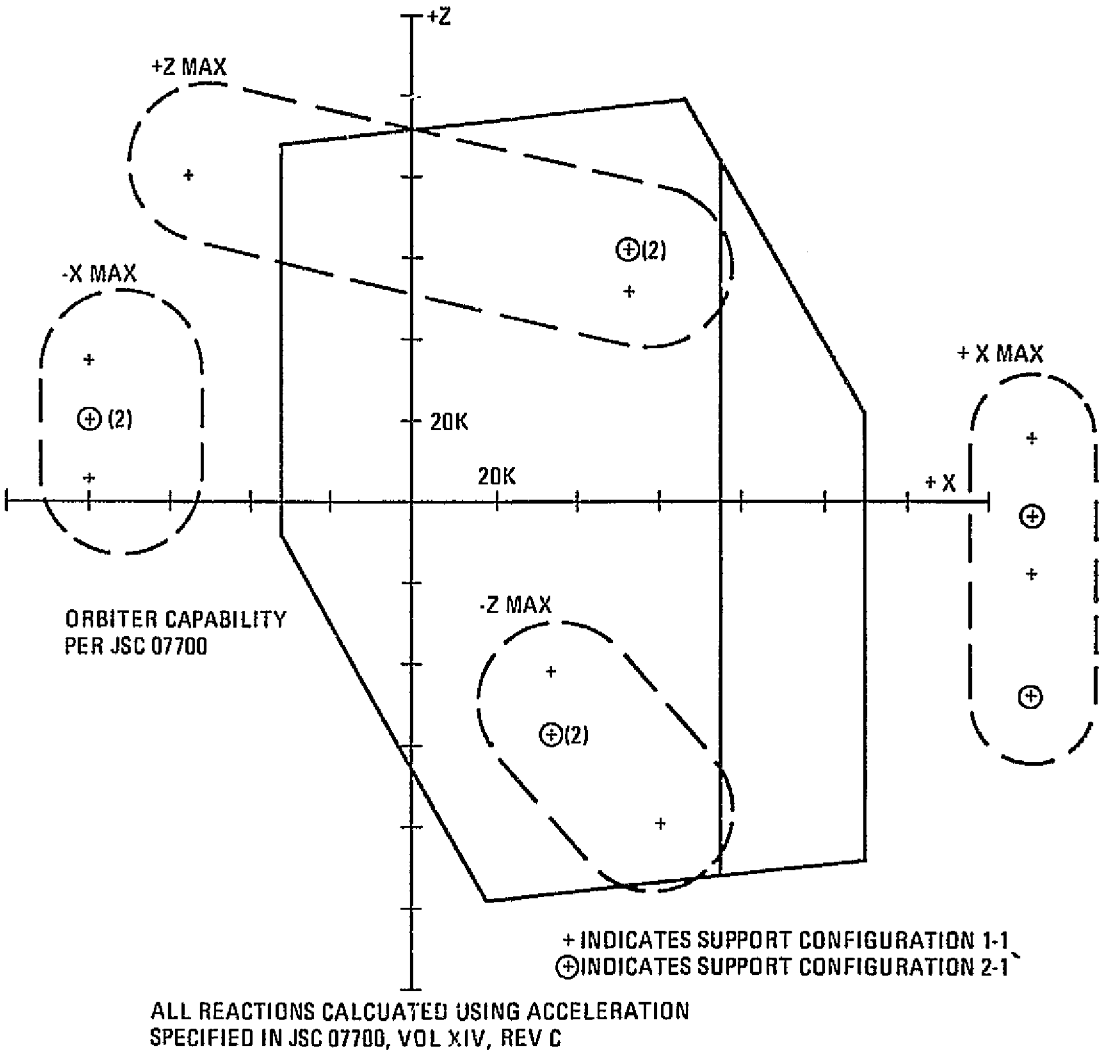


Figure 5-12. X/Z Interaction at X_0 1246/Z_0 414/Y_0 +94 for Baseline Tug Using Current Orbiter Provisions

suitable deployment adapter aft frame modification will preclude any adapter interference. This engine bell encroachment of Orbiter space is expected to be permissible since both Tug and Orbiter are unloaded at this time, and therefore neither is deflected from nominal configuration.

IMPACT DESCRIPTION:

Design of new bridge beam.

Redesign of X_0 1303/Z_0 409 region to provide aft interface for new beam.

Minor redesign of X_0 1307 bulkhead to provide attach bracket for support truss X-reaction link.

Documentation update in JSC 07700, Vol. XIV, to define capability of new provisions.

IMPACT OF NONINCORPORATION:

Insufficient Orbiter structural support capability to accommodate Tug.

RECOMMENDATION/REMARKS

Incoporation of the above assures Tug/Orbiter structural compatibility for JSC accelerations. Failure to incoporate may result in insufficient Orbiter structural capability for Tug/Spacecraft missions.

Note 1: Subsequent to submittal of this request, the six-point redundant support concept was recommended for Tug. Although this change is no longer applicable to Tug, it may be needed by other Orbiter payloads.

5.21 GDC 021, TLM INPUT REQUIREMENTS NO. 2

CHANGE TITLE:

Orbiter/Payloads Telemetry Inputs Requirements Modification 2

DESCRIPTION OF CHANGE:

Modify JSC 07700, Section 14.2.1 and/or 14.2.2 (Payload Data Interleaver and Payload Signal Processor) to:

a. Permit multiple payload telemetry data from attached payloads to be input to the payload signal processor(s).

or

b. Add bit synchronization and frame synchronization logic to the Payload Data Interleaver.

REASON FOR CHANGE:

The current PSP/PDI configuration has the disadvantage that payloads (Tug, plus to three spacecraft) with multiple telemetry outputs must interface with the less desirable PDI because of the single input channel capability of the PSP.

The PDI interface is less desirable than the PSP because up to three extra TSP inputs are required per channel for clocking, and PCM frame synchronization signals from the payloads. Thus, extra payload hardware/software is required for attached Orbiter operation when interfacing with the PDI (these signals are not required during detached operations or when interfacing with the PSP because it performs the frame sync operations automatically). Two possible solutions to this problem are indicated in "a" and "b" above. Change "a" increases the input capability of the PSP. Change "b" solves the problem by making the input interfaces the same for both the PSP and the PDI.

IMPACT DESCRIPTION:

Part "a" of this change requires revision to Orbiter payload signal processor to provide the desired multiple input capability. This proposed change could eliminate the requirement for the PDI unit for all Orbiter payloads and thus result in a possible Orbiter cost reduction.

Part "b" of this change requires modification to the PDI to incorporate additional logic to perform Bit and frame synchronization for each of that unit's five input channels.

IMPACT OF NONINCORPORATION:

Nonincorporation causes size and complexity of payload/Orbiter downlink interface to remain high and results in higher costs for the majority of Orbiter payloads designed to be deployed from the Orbiter.

5.22 GDC 022, CREW CABIN I/F

CHANGE TITLE:

Orbiter/Tug Aft Crew Cabin Interface with Orbiter Payload Support Avionics

DESCRIPTION OF CHANGE:

Modify JSC 07700, Volume XIV, Section 14, to clarify and expand the Orbiter's payload support capability to allow (permit) payload unique support equipment located at the MSS to communicate with the Orbiter payload support electronics such as the payload MDM units.

REASON FOR CHANGE:

JSC 07700 provides accommodations for payload unique support equipment in the MSS and PSS proportions of the Orbiter aft crew cabin but it does not state that this payload unique support equipment may communicate with the Orbiter payload support electronics.

The baseline Tug/IUS interface concept assumes an interface between the Tug/IUS unique control panels located at the MSS and the payload MDM units (Figures 5-13 and 5-14).

IMPACT DESCRIPTION:

The impact resulting from this change consists of JSC 07700 documentation update only since this capability is inherently available in the present NAR Orbiter design.

IMPACT ON NONINCORPORATION:

Nonincorporation would severely limit the usefulness of the Orbiter's payload support electronics and complicate payload interface design and operations.

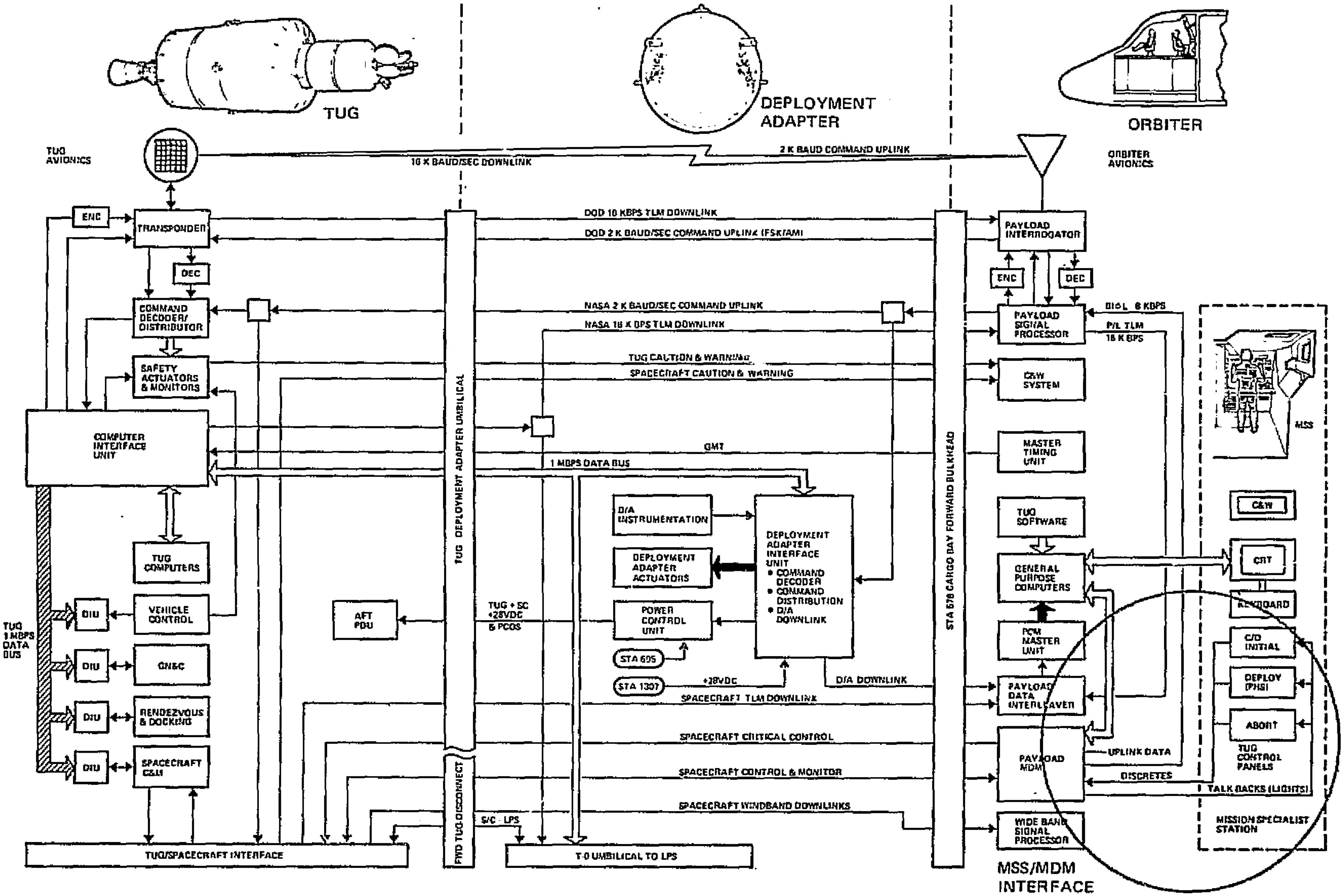


Figure 5-13. Recommended Tug Control/Orbiter Avionics Interfaces

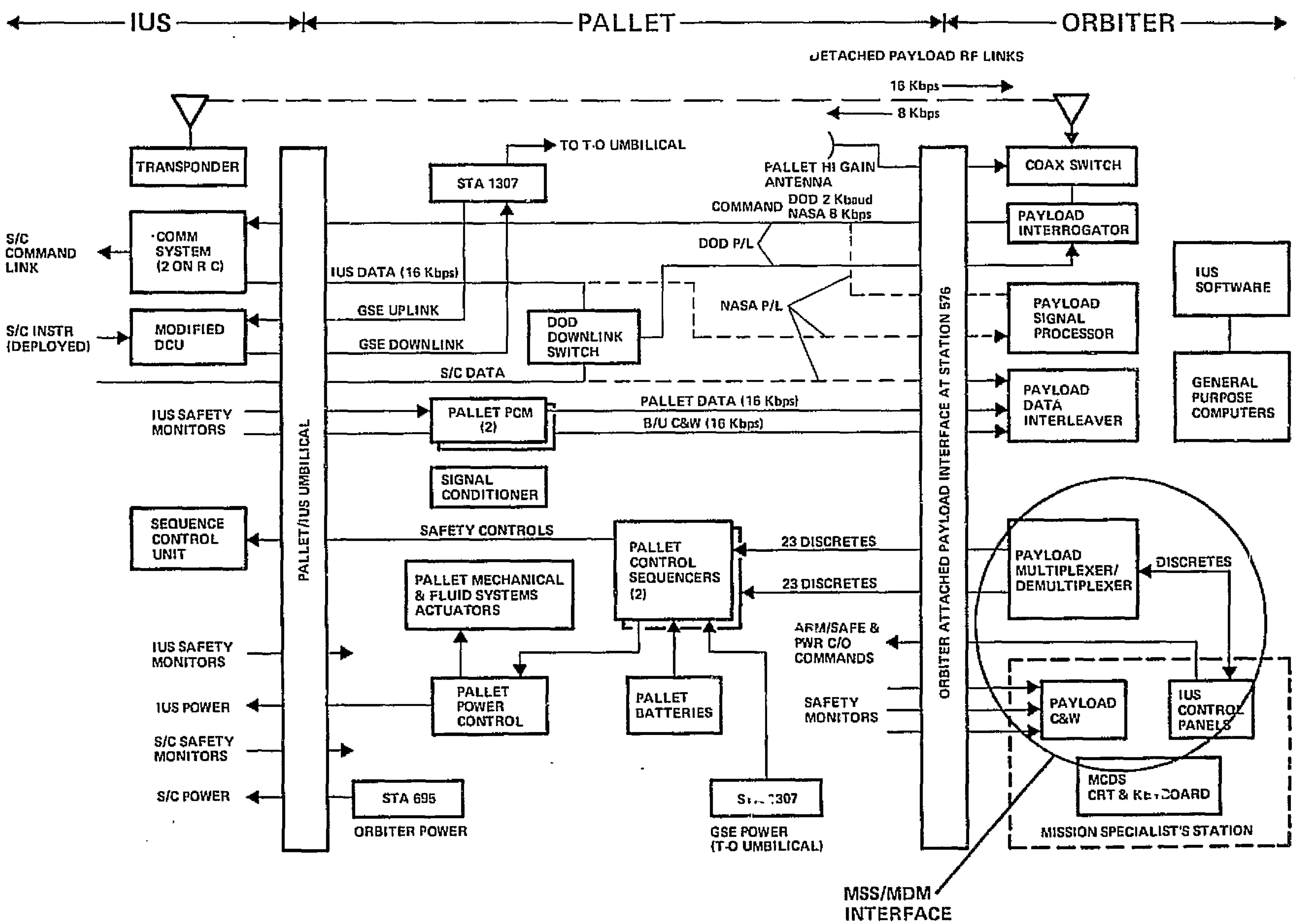


Figure 5-14. Typical IUS MSS/Orbiter Avionics Interface

SECTION 6

PROPOSED TUG INTERFACE REVISIONS

The MSFC baseline Tug, described in 68M00039-2, was used by the interface study as the starting point for developing Tug/Orbiter interface requirements. While this work was in progress, proposed changes to the Tug vehicle were identified to improve its interface compatibility with study generated peripheral equipment and NASA defined Orbiter accommodations.

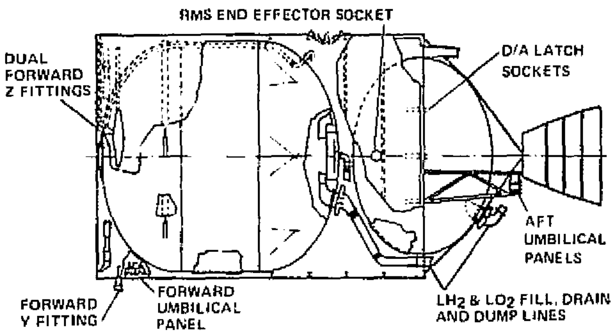


Figure 6-1. Recommended Baseline Tug Revisions

These proposed revisions improved the MSFC baseline Tug interface implementation and operations. The items identified in the following text are recommended Tug revisions based entirely on study work to make Tug compatible with the recommended support/deployment/operations concept. Figure 6-1 depicts the Tug configuration with these revisions included.

Structural Attachments. Three forward X_o 951 attachments (two Z and one Y) and no aft Tug attachments (all on D/A to improve Tug performance) are employed with the recommended six point redundant support concept. Preliminary fitting designs were prepared.

Structural Shell Design. The revised support fitting configuration, flight acceleration model, and latch configuration have resulted in recommended shell revisions including: use of composite frames, addition of latch longerons, and definition of face sheet reenforcements.

LH_2 and LO_2 Fill, Drain and Dump. An increase in LH_2 fill, drain and dump line size has resulted from a recent Shuttle decision to dump both Tug propellants. In addition, minor changes in both LH_2 and LO_2 dump line routings are recommended to minimize line diameter requirements.

Forward Umbilical Panel. The recommended incorporation of a forward cargo bay floor-mounted payload service panel results in the requirement for a matching forward portion on the Tug shell.

Aft Umbilical Panels. Preliminary design activity associated with the development adapter has resulted in minor revisions to the Tug/deployment adapter (D/A) separation plane, specifically involving umbilical panel location.

D/A Latches. Finite element modeling of the Tug and D/A has shown that the latches nearest the X longeron experience no tension, whereas those nearest the top and bottom centerlines experience maximum tension for non-crash load conditions. However, the separation plane is subjected to maximum total tension during the crash condition, and the resulting latch tension loads are highly concentrated near the X longerons.

Comparison of an alternative 11-latch system with the original 16-latch system resulted in selection of the 11-latch concept, which provided latches at points of maximum load (near top and bottom centerlines and X longerons) and eliminated those at lightly loaded locations. The original $\pi/8$ spacing was maintained to permit integration of the latch longeron array with the symmetrical LO_2 tank support longeron array, and the final total of 11 was achieved by simply omitting latches and longerons at five locations.

RMS Attachment Socket. A single tri-latch type probe socket for Tug handling with RMS during deployment/retrieval is located at X_o 1140, Y_o 88, and Z_o 400 on the Tug structural shell.

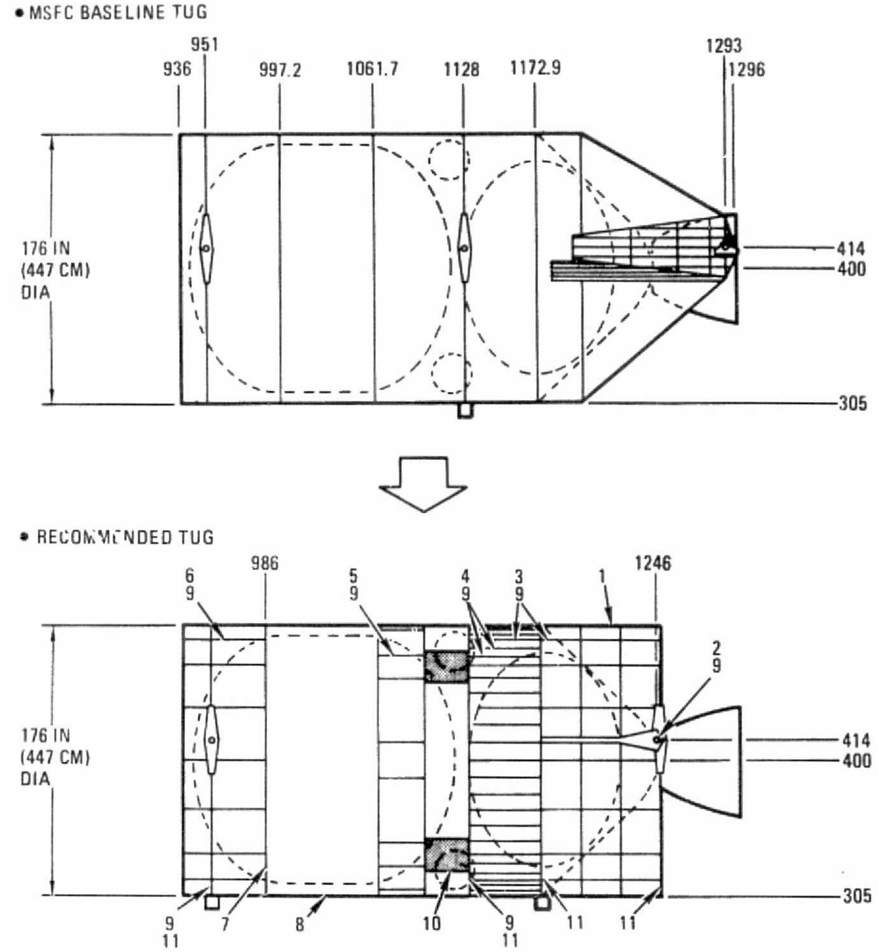
The following sections address some of these proposed revisions in greater detail. An inboard profile of Tug plus deployment adapter, in Figure 4-2 of Section 4 of this volume, reflects these proposed changes to the MSFC baseline Tug.

6.1 STRUCTURES

The reference Tug vehicle structure was derived from the NASA baseline Tug defined in MSFC 68M00039-2 and shown on NASA drawing 10M23300. Overall dimensional characteristics (length, diameter, propellant tank volumes) of the Tug itself remain unchanged but several revisions were made to the body structure. Figure 6-2 shows the NASA baseline and updated study reference Tugs and identifies the differences. Figures 6-3 and 6-4 further define the basic sandwich sidewall and solid laminate pans incorporated in the reference configuration body structure to simplify longeron attachment and to aid load introduction and distribution into the thin sidewall facings. To decrease weight yet provide increased stiffness, the all-composite major frame concept shown in Figure 6-5 was adopted.

6.1.1 FRAMES. Initially, major frames were sized based on bending moment distributions derived from existing Convair STSS data to modify conventional shell-supported frame moment distributions. A substantial reduction in peak moments and a narrowing of the affected arc resulted when compared with identically loaded free rings. The reduction was mainly due to sidewall shear restraint and indicated that lighter frames than those previously selected would be adequate for resisting the moments induced by Orbiter support reactions.

However, to maintain the analogy with the STSS data (upon which the moment reductions were predicated), it was necessary to maintain a ratio of frame bending stiffness to shell shear stiffness similar to that in the STSS. Since the current sidewall material



REVISION SUMMARY

ITEM	DESCRIPTION	BASIS
1	REPLACE BIFURCATED ADAPTER WITH CYLINDRICAL ADAPTER	LIGHTER; HIGHER ±Y STIFFNESS
2	RELOCATE X-SUPPORT/PIVOT AND Y KEEL SUPPORT ADD SECOND Y KEEL FITTING	ORBITER HAS SUPPORTS AT X_0 1246, 1303 ONLY; ENGINE VIOLATES ENVELOPE USING X_0 1303 PIVOT
3	ADD LATCH LONGERONS TO TUG & ADAPTER	
4	ADD OXIDIZER TANK SUPPORT LONGERONS TO TUG	INTRODUCE CONCENTRATED LOADS TO SHELL
5	ADD FUEL TANK SUPPORT LONGERONS TO TUG	
6	ADD SPACECRAFT SUPPORT LONGERONS TO TUG	
7	REPLACE FUEL TANK FWD SUPPORT ROLLERS WITH TANGENTIAL STRUTS; REVISE/RELOCATE LOAD RING	LIGHTER; STIFFER; CONTINUALLY LOAD – CARRYING
8	REVISE BASIC SANDWICH SIDEWALL	CONVAIR IRAD POINT DESIGN (FIGURE 6-3)
9	PROVIDE SOLID LAMINATE "PANS" IN SIDEWALL AT LONGERONS & INTERFACE FRAMES, FITTINGS	SIMPLIFY ATTACHMENT; DISTRIBUTE LOADS INTO SIDEWALL (FIGURE 6-4)
10	CLOCK ACPS ARRAY 45 DEG	AVOID IMPINGEMENT ON SUPPORT FITTINGS
11	REPLACE MAJOR FRAMES WITH ALL – COMPOSITES CONCEPT	LIGHTER; STIFFER (FIGURE 6-5)

Figure 6-2. Update of MSFC Baseline Tug to Study Reference Configuration

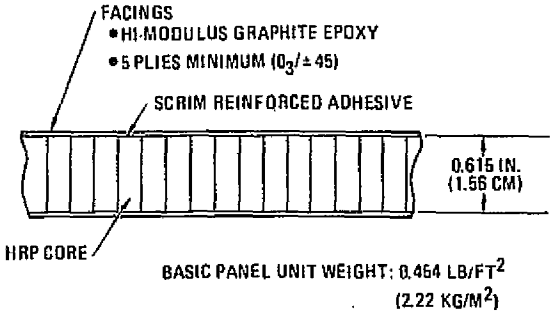


Figure 6-3. Basic Sandwich Sidewall

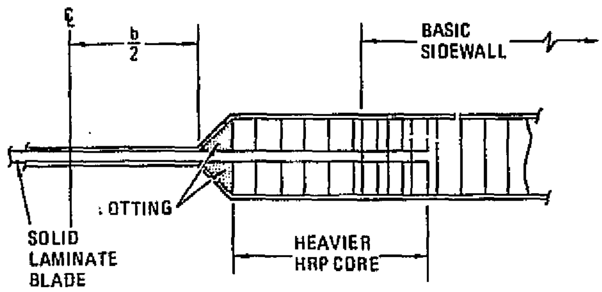


Figure 6-4. Solid Laminate Pan Concept

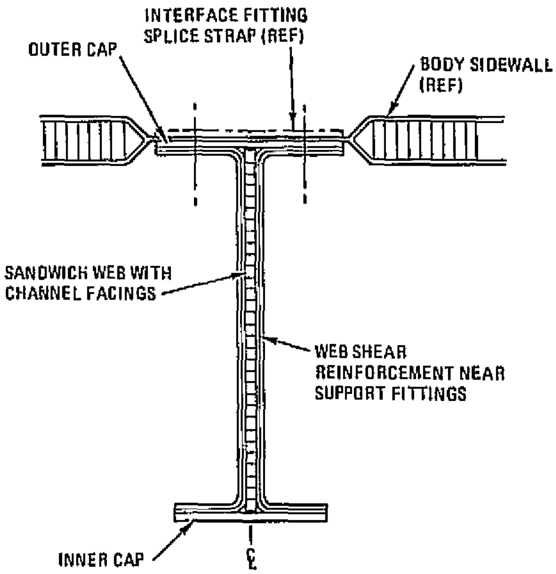


Figure 6-5. Major Frame Concept

and construction was similar to the STSS, frame EI had to approximate that used in STSS. However, since frame weight reduction was accompanied with depth reduction to maintain balanced proportions, the moment of inertia also decreased. To maintain EI, an increase in E was therefore necessary. Since the STSS frames were aluminum, the required modulus increase could be achieved by using high-modulus graphite/epoxy for the current frames.

Accordingly, the frame concept shown in Figure 6-5 was incorporated at all major load locations in the Tug. It employed high-modulus graphite/epoxy (HM-S/X-904 or equivalent) for all solid laminate elements, sandwich construction for the web (with Hexcel HRP core), and a scrim-reinforced adhesive for the web channel/core bond.

Tangential loads were introduced into the frames through an assumed "pan" in the body sidewall sandwich. Web reinforcement (to accommodate high shear flows in the web adjacent to the load introduction points) was also provided. The web channel facings were limited to a minimum thickness of four plies (with 100% ±45-degree ply orientation), and the caps used 100% unidirectional ply orientation (except for the web channel plies, which were conservatively omitted in flange thickness determination). Equal areas were employed in both the inner and outer caps. The outer cap width was held constant at 3.00 in. (7.5 cm) whereas the inner caps were proportioned to achieve fully effective flange material.

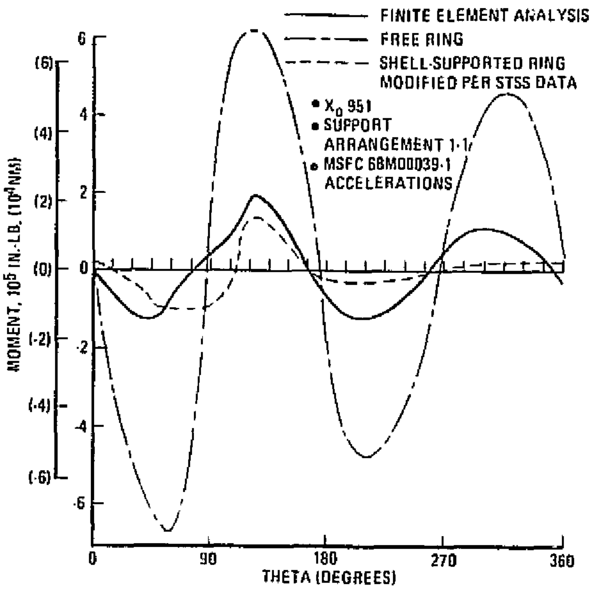


Figure 6-6. Frame Moments: Comparison of Finite Element Data with Preliminary Screening Data

In the subsequent finite element analysis, data was generated giving frame axial and shear force distributions in addition to more representative moment distributions. Figure 6-6 compares the latest moment distribution at X_0 951 with the data used for initial frame sizing and confirms the moment reductions upon which initial frame sizing was based.

Frame weight data was developed parametrically (as a function of depth) to reflect cap and web sizing based on the latest bending moment. A nominal depth of 8.0 inches (20.3 cm) was selected as a basis for cap sizing at all locations (except X_0 1181 in the D/A, where a depth of 6.0 inches (15.2 cm) was required to provide sufficient clearance from the oxidizer tank supports).

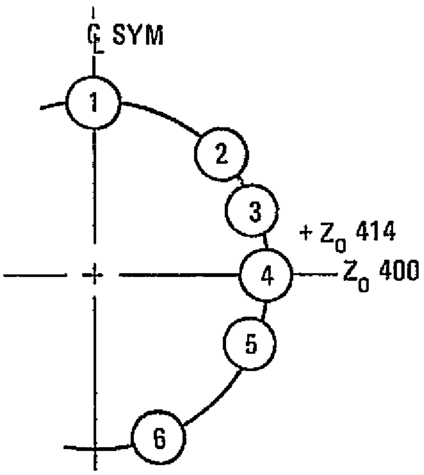
6.1.2 LATCH LONGERONS. Latch longerons are required in 11 places to collect and transmit Tug inertia loads across the Tug/adapter interface. The latches are arranged as shown in Figure 6-7. All longerons are sized for the maximum load indicated. The longerons extend forward from X_0 1172.9 to X_0 1127, and a frame centered at X_0 1128 is provided for longeron termination. The Tug shell is "panned" under the longerons as in Figure 6-4.

Cross-section areas at loaded end and opposite end are the same as on the adapter, and the area varies linearly between the ends. End pads are the same as on the adapter and docking guides (configuration TBD) are assumed integral with longerons.

6.1.3 SHELL FACINGS. Reinforcements on Tug shell have been configured for the recommended six-point D/A support concept. The reinforcement flat pattern is shown in Figure 6-8.

6.1.4 SUPPORT FITTINGS. Tug forward Z and Y preliminary support fitting designs were developed. Table 6-1 summarizes fitting design data and reference criteria. Figures 6-9 and 6-10 present recommended configurations for Tug Z and Y support fittings respectively.

The bearing subassembly, comprised of spherical segment, outer race, and inner liner, was assumed to be covered by Rockwell specification to assure compatibility with the Orbiter cargo retention system.



LOCATION	TENSION LOAD	
	LB	N
1	22090	98301
2	12450	55430
3	18676	83108
4	18676	83108
5	12450	55403
6	21353	95021

Figure 6-7. Latch System Arrangement and Loads

The shaft subassembly consists of a turned shaft plus threaded caps at each end. The shaft is steel or other alloy of 260–300 ksi (1790–2070 MPa) tensile strength to provide the required +25% margin of safety under maximum loads. Load transfer from shaft to fitting is accomplished entirely in bearing to eliminate a shaft/fitting blending radius and thereby minimize the effective overhang of the applied load and maximize fatigue life. Incorporation of matching shallow tapers on the shaft and its support bushings also permits ease of installation and removal and provides a reaction for any inboard thrust due to Y-direction friction between the bearing subassembly and the shaft. Any outboard friction is resisted by the inner cap.

The fitting subassembly is comprised of a titanium weldment and the two shaft support bushings. The weldment consists of two Z beams machined in detail then electron-beam welded to a central hub. Loads are sheared from the fitting beams into the outer surface of the composite shell structure through fully bonded plus mechanically fastened joints. The outside portion of the fitting subassembly is configured without gussets to provide a flanged cylindrical hub. The hub OD provides a grip surface for the KSC AGE system yet minimizes total fitting weight by providing a support at the fartherest permissible outboard location on the smaller diameter shaft, thereby minimizing shaft bending moment.

A Y fitting design similar to that used for Tug at station 951 is shown in Figure 6-10. The installation consists of a steel cap mounted on a machined aluminum beam, in turn supported by the composite shell at the station X_0 951 major frame.

The steel cap provides surfaces that contact the Orbiter bridge beams during installation, removal, and load transfer, and is attached to the beam by mechanical fasteners to accommodate replacement. The beam is machined in one piece from a titanium forging. At station 951, sufficient depth is available to permit the beam to mount on the shell outer surface.

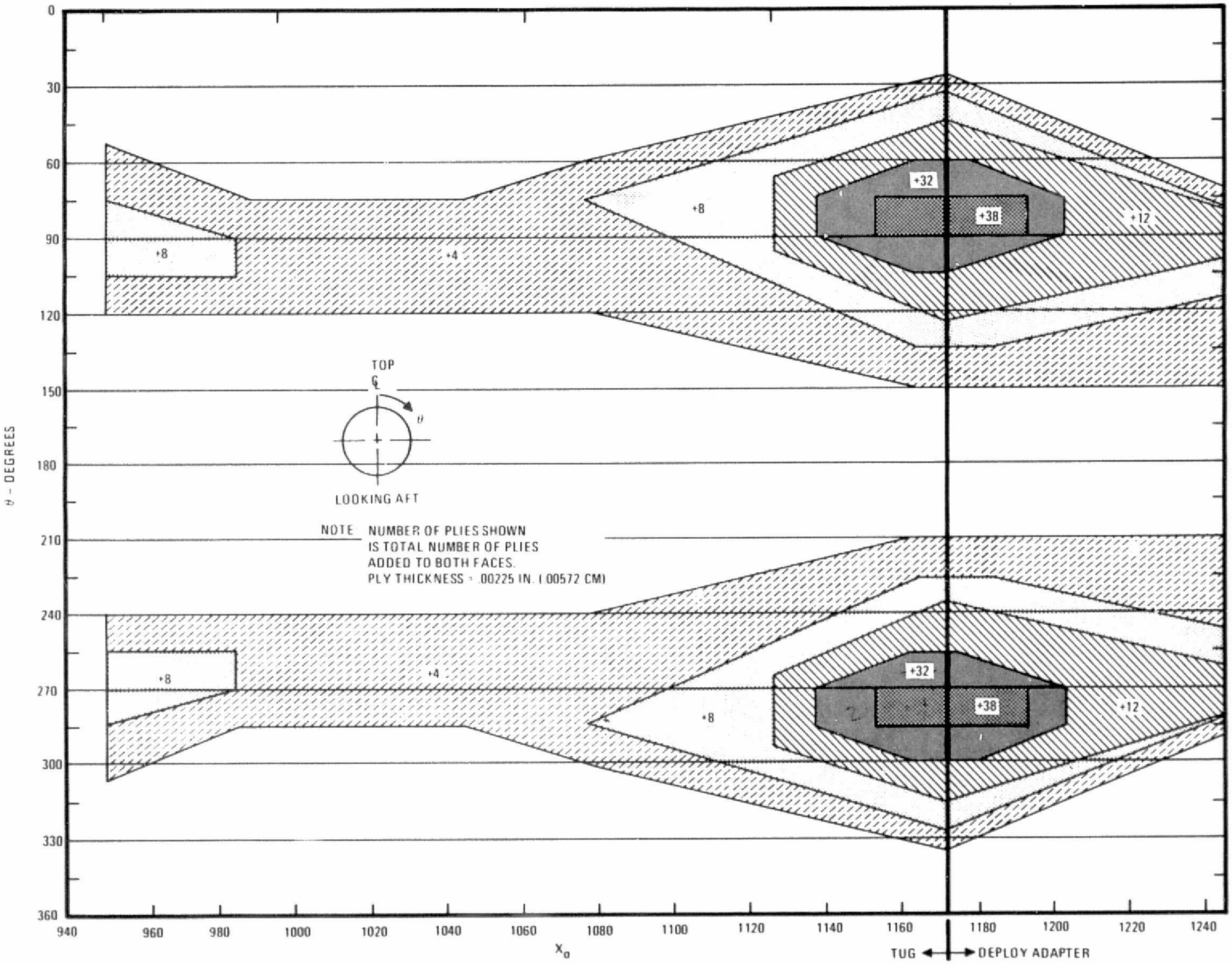


Figure 6-8. Shell Reinforcement

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Table 6-1. Support Fitting Design Criteria

Item	Characteristic	Basis
Shaft Diameter, in. (cm)	3.25 (8.25)	JSC Chart: NASA-5-75-10004 MSFC Dwg.: 30A90707 KSC Dwg.: PRC-0538-6
Bearing, in. (cm)		
Width	2.00 (5.08)	RI L/O: VL70-544105
Diameter	4.00 (10.16)	JSC Chart: (same)
Y-Motion, in. (cm)		
Outboard	2.00 (5.08)	RI L/O (same) + 0.50 in. (1.27 cm Tug motion
Inboard	1.50 (2.81)	JSC Chart: (same)
Loads		
Accelerations	New MSFC	MSFC PF 02-75-31
Safety Factors	1.4/1.1	MSFC-HDBK-505
Margin	+0.25	MSFC 68M00039-1
Friction		
±Y	$\mu = 0.1$	NASA request
±X, ±Z	$\mu = 0.1$	Section 4.2.3.2, Vol. II
AGE Configuration	New KSC	KSC drawing (same)

6.2 MECHANISMS

Proposed Tug mechanisms revisions include the RMS and effector socket and retrieval alignment guides and aids.

6.2.1 RMS SOCKET. The RMS socket is located in the Tug structural shell at X_O 1140, Y -88 and Z 400 as shown in Figure 4-2 of this volume. This position was selected since it corresponds to Tug plus payload cg placement for the maximum weight Tug deployment condition and is adjacent to a Tug frame. The relative Tug and RMS positions for deployment/retrieval that result from this socket location are depicted in Figure 6-11.

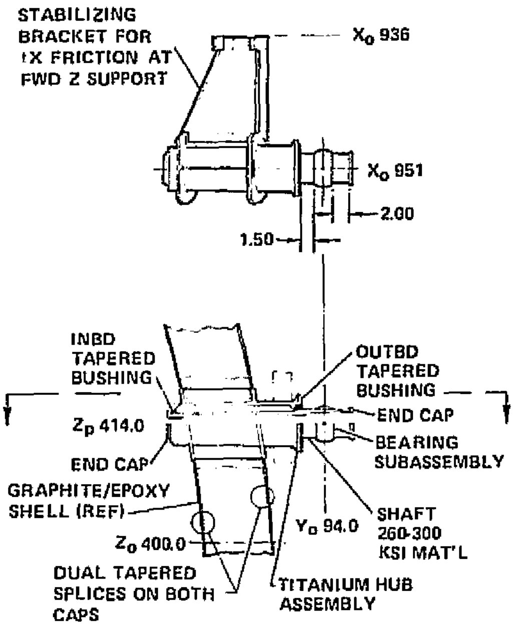


Figure 6-9. Typical Z Support Fitting

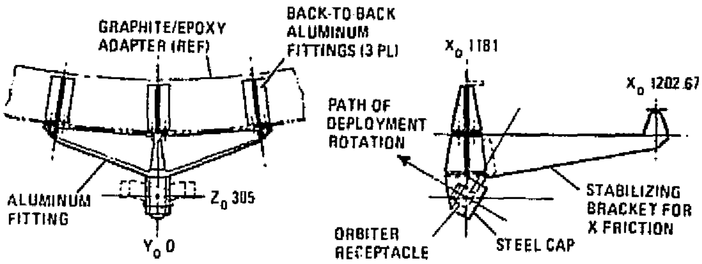


Figure 6-10. Typical Y Support Fitting

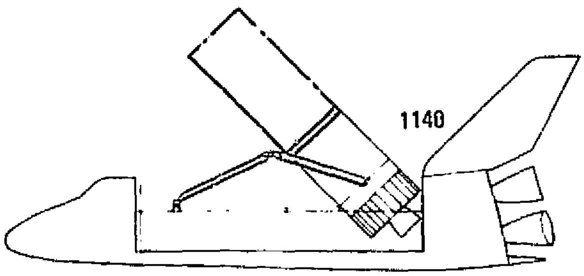


Figure 6-11. RMS/Tug Attachment

6.2.2 ALIGNMENT GUIDES. Tug alignment guides and positioning aids are all associated with deployment adapter deployment and insertion operations. Tug devices used to aid these operations include a TV camera target, umbilical panel support struts, and the latch longerons. Details of alignment requirements for these D/A related devices are contained in Section 4.2 of this volume.

6.3 FLUIDS

Investigation of propellant abort dump resulted in proposed revisions to the Tug fill, drain, and dump ducting configuration. Propellant dump for the Tug is accomplished by pressurizing the propellant tanks and dumping both main propellants through lines that exit the Orbiter through the T-0 panels. Configuration of the entire dump system, including an assumed routing of the Orbiter-mounted portions of the lines, is shown in Figures 6-12 and 6-13. Since both the LH_2 and LO_2 dump lines have a large vertical drop and are under high acceleration (F/W) during RTLS dump, the total pressures at the top of the lines are substantially lower than at the exit. This is particularly true for LO_2 because of its high density. Due to this pressure drop, choking in the vicinity of the propellant tank outlets may occur.

The Orbiter exit was found to be the control section for the LH_2 system (exit chokes before the tank outlet) allowing use of a constant diameter line from outlet to exit. For the LO_2 system, however, the tank outlet section was found to choke before the Orbiter exit at low liquid levels near the end of dump. To obtain the required flowrates, the duct diameter required in the vicinity of the propellant tank outlet is larger than at the exit. This larger diameter must be maintained down the line to a point where increasing pressure due to increasing elevation head offsets the frictional

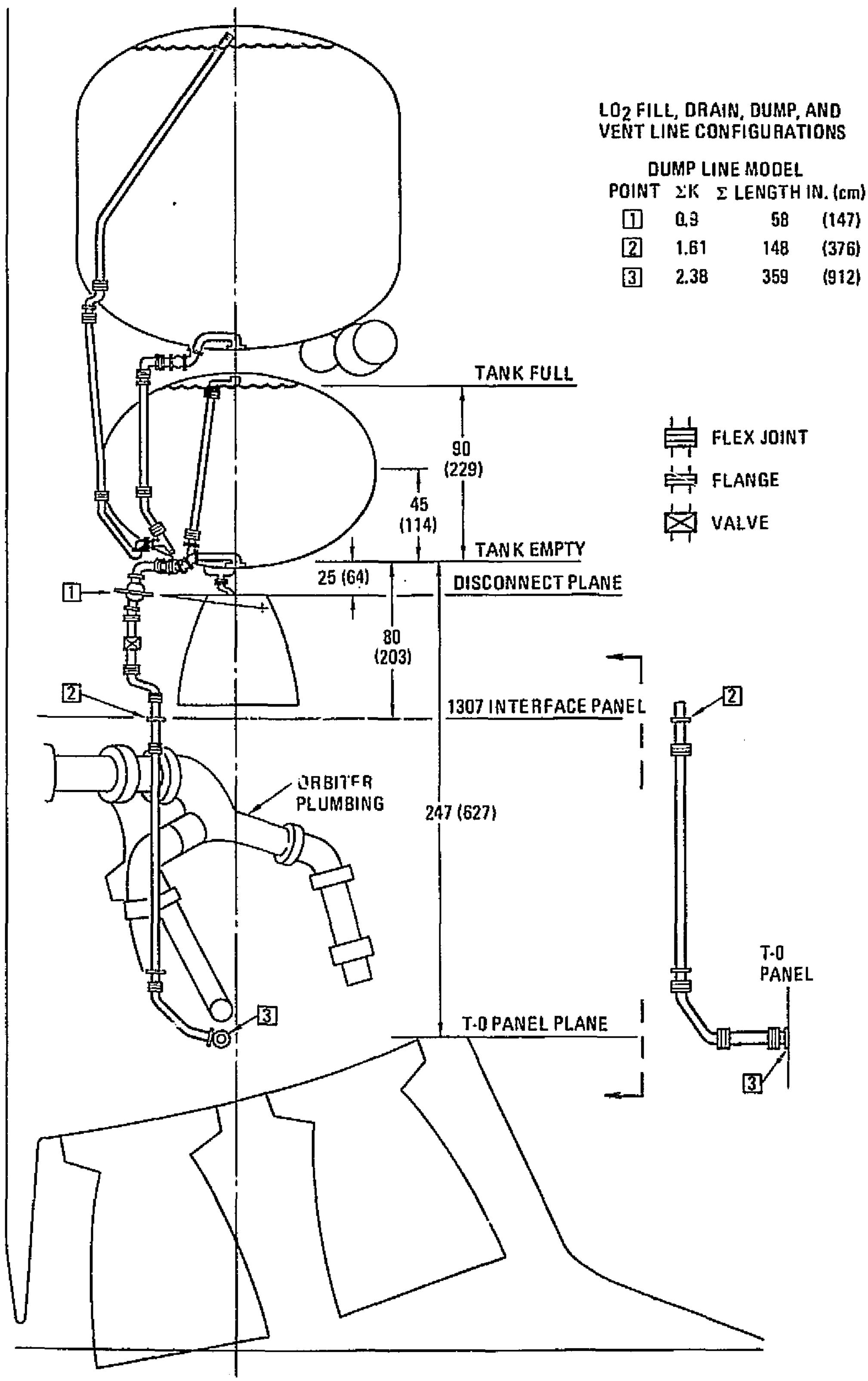


Figure 6-12. LO_2 Fill, Drain, Dump, and Vent Line Configurations

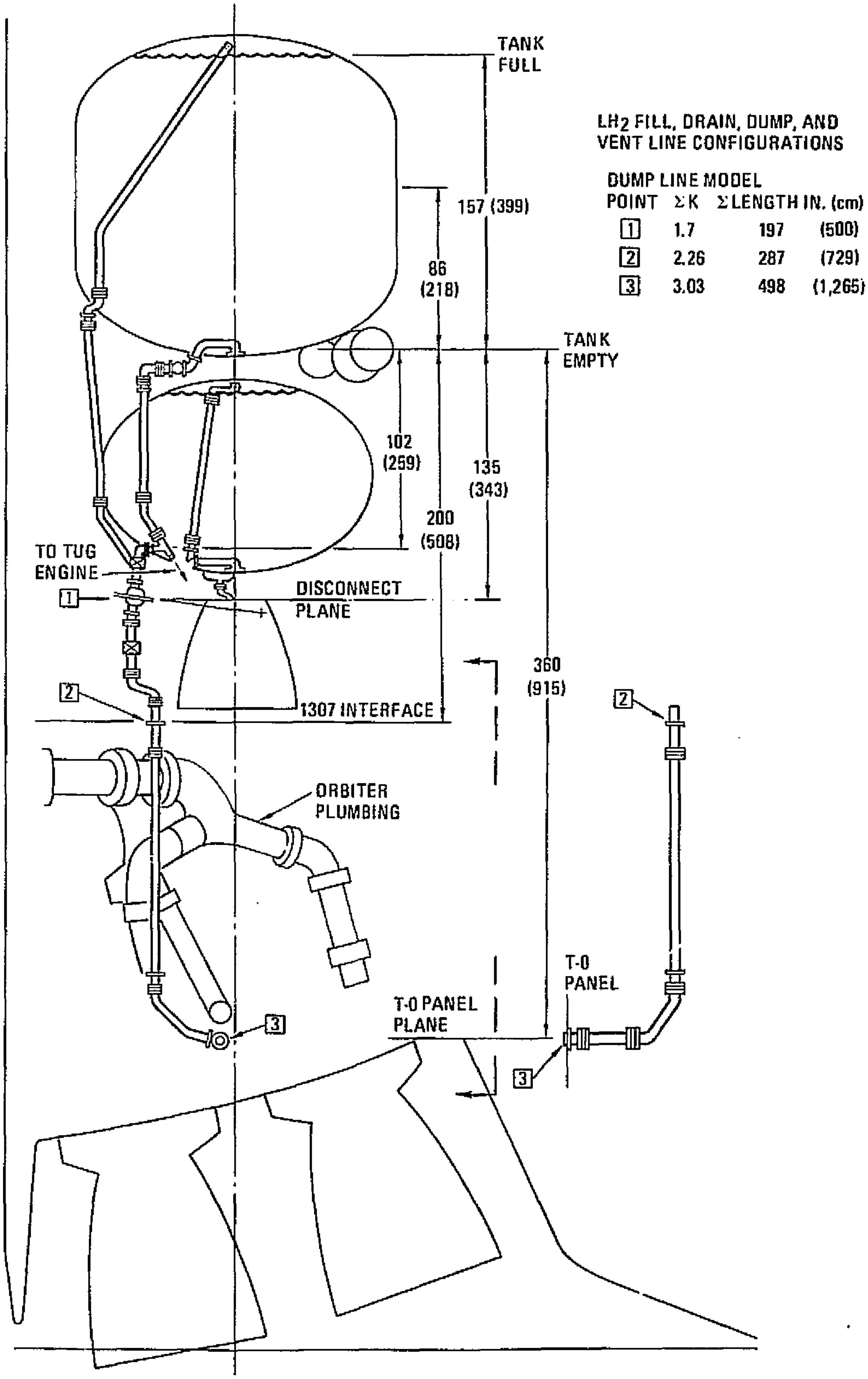


Figure 6-13. LH_2 Fill, Drain, Dump, and Vent Line Configurations

pressure loss, allowing a reduction in diameter, which can be maintained to the exit. For this reason, the outlet duct design should be as clean (low ΔP) as possible and should drop at the fastest possible rate (maximum slope). The cleanest practicable outlet line design using the baseline routing with "inverted" pickup and horizontal run to the vicinity of the disconnect was used for the optimization analysis in Volume II.

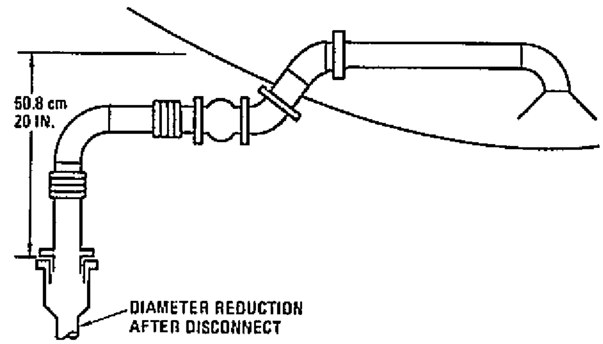


Figure 6-14. Outlet Duct Design

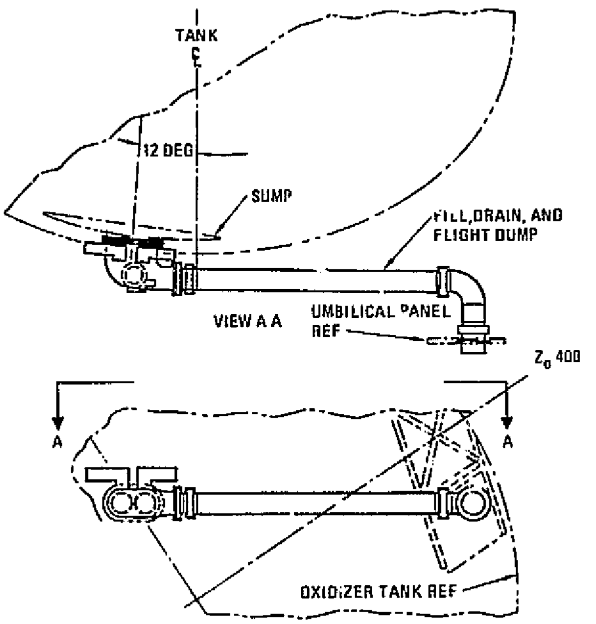


Figure 6-15. Recommended LO_2 Tank Outlet Configuration

For this configuration, shown in Figure 6-14, the larger outlet diameter must be maintained past the Tug/disconnect, as shown. An alternative configuration without the inverted pickup, shown in Figure 6-15, is recommended.

6.4 UMBILICAL PANEL SERVICES

The Tug has four umbilical panels used for transmission of Tug and payload services. These are:

a. The fuel panel between Tug and deployment adapter, located on the Tug -Y (port) side at X_0 1246 and Z 380.

b. The oxidizer panel between Tug and deployment adapter, located on the Tug +Y (starboard) side at X_0 1246 and Z 380.

c. The electrical panel between Tug and deployment adapter, located at the station 1172.9 structural interface.

d. The payload service panel between Tug and Orbiter, located on the Tug shell at X_0 961, Y -30, Z $\sim$ 310.

Panel configurations are adequately described in Figure 4-2 of Section 4 in this volume. Additional information on the forward panel is contained in Section 2. Details of fluid and electrical services using the three Tug-to-D/A panels are contained in Section 4.

SECTION 7

IUS/TUG INTERFACE COMPARISON

The IUS/Tug interface comparison, performed as Study Task 6, investigated IUS interface requirements for their similarity with Tug and scrutinized areas that were compatible. Conflicting requirement areas were of special interest due to the possible interface revisions involved for IUS-to-Tug transition.

Figure 7-1 indicates the flow logic used to accomplish Task 6. Because up-to-date information for the five candidate IUS vehicles was not available, the first major effort in the IUS/Tug comparison task involved update of previously published vehicle data to reflect USAF performance and configuration requirements, and recent changes in planned Orbiter accommodations for payloads. Although NASA and USAF-funded contractor studies had been accomplished (and were currently in progress) on both expendable and reusable versions of many IUS candidates, the comparative evaluation performed by the Interface Study was limited to expendable IUS candidates only.

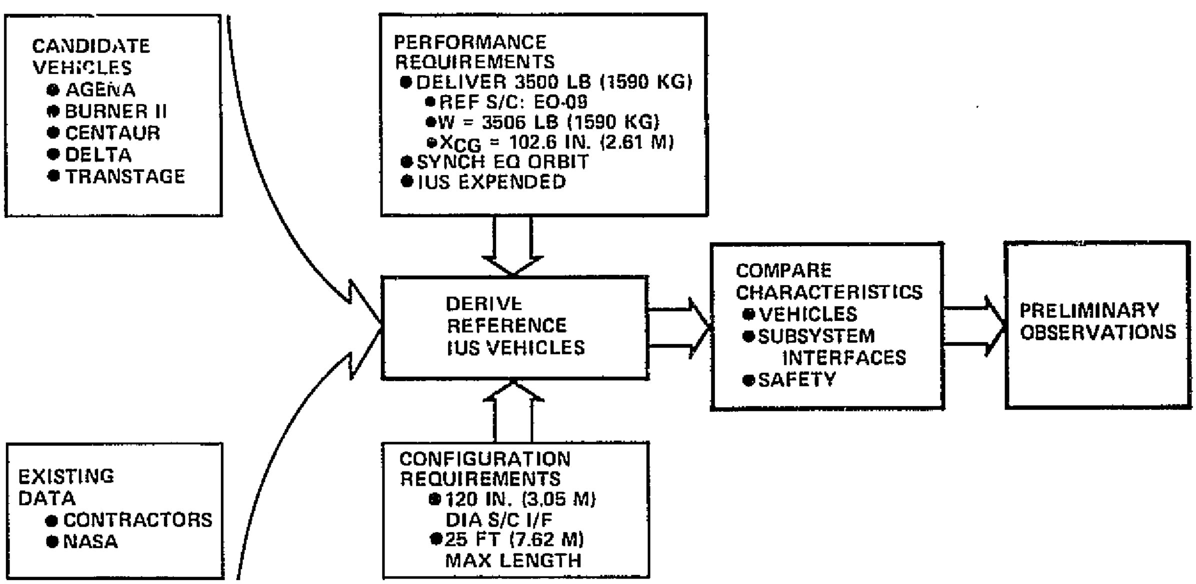


Figure 7-1. IUS/Tug Interface Comparison

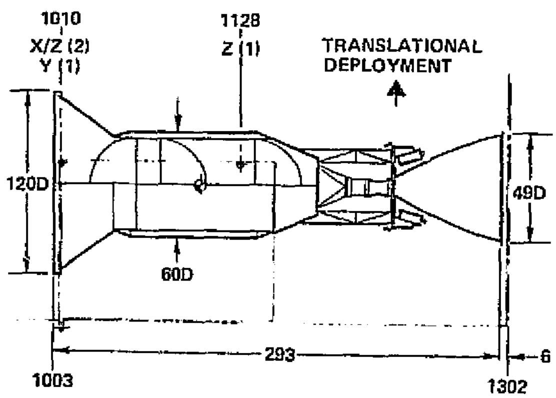
Once the five expendable IUS vehicles were fully defined, a comparative investigation of individual vehicle characteristics plus six interface areas was performed with reference to MSFC baseline Tug characteristics and the Tug interface requirements developed during Tasks 1 through 5 of the Interface Study. Comparisons were accomplished for structural, mechanical, fluid, environmental, and avionics interfaces plus interface safety. A summary compilation of these interface comparisons was generated and appropriate preliminary observations of comparison results noted.

7.1 IUS REFERENCE DOCUMENTATION

Figures 7-2 through 7-6 contain the reference IUS vehicle configurations used for interface comparison purposes in Study Task 6. These configurations were developed by Convair from previously published contractor work. The candidate vehicles are all derivatives of currently flying upper stage lauch vehicles: Agena, Burner II, Centaur, Delta, and Transtage. The current vehicle configurations must all be modified in varying degrees to meet the USAF minimum performance requirements (3500 lb (1590 kg) synchronous equatorial payload delivery) and configuration constraints (120 in. (3.05 m) diameter P/L interface and 25 ft (7.62 m) maximum vehicle length). Changes were also needed to conform to Shuttle physical interface accommodations and operating techniques. Each chart references the initial source material used and indicates the major changes made to yield vehicle conformance with the new performance/configuration requirements. A sketch of the vehicle configuration, including its mounting location and assumed support provisions in the Orbiter payload bay, is shown for each of the IUS candidates along with a table containing principal vehicle characteristics. Since this investigation was accomplished strictly for comparative purposes, English units only are contained in the following figures.

- BASIS
  - BASELINE CONFIGURATION
    - NASA CR-121273, "COMPATIBILITY OF AGENA UPPER STAGE WITH SPACE SHUTTLE"
  - CHANGES
    - FUEL TANK $\Delta L = +8$ IN.
    - NOZZLE $\Delta L = +37$ IN.
    - FUEL = UDMH → MMH
    - AVIONICS MODULE = 120 IN. DIA

- CONFIGURATION



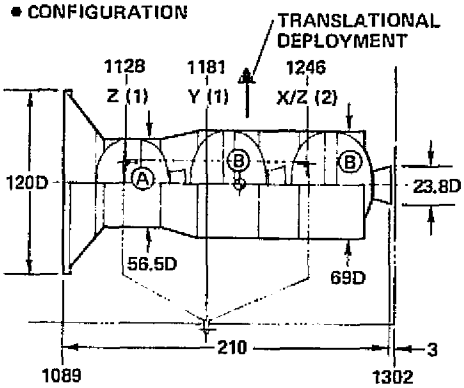
- CHARACTERISTICS

	W (LB)	XCG (STA)
MAIN PROPULSION	STORABLE	
• ENGINE = T (LB)	16,000	
ISP (SEC)	321	
E	100	
MR (O/F)	2.03	
• OXIDIZER	HDA	
DENSITY (PCF)	101.8	
TOTAL (LB)	9,940	
USABLE (LB)	9,806.	
• FUEL	MMH + SO	
DENSITY (PCF)	54.54	
TOTAL (LB)	4,896	
USABLE (LB)	4,830	
ACPS	N_2H_4	
MASS PROPERTIES	W (LB)	XCG (STA)
• VEHICLE = W_F (B/O)	1,500	—
W_I (SEP'N)	16,432	—
• SUPPORT STRUCTURE	1,295	—
• SUPPORTED = ASCENT	17,727	1100.71
ABORT	3,091	
PERFORMANCE (LB)	3,566	

Figure 7-2. Reference Configuration I — Agena IUS

- BASIS
  - BASELINE
    - NASA CR-121152 "BURNER II/SHUTTLE INTEGRATION STUDY"
    - AIAA PAPER 74-1091 "EXPENDABLE S.R.M. UPPER STAGES FOR SPACE SHUTTLE"
  - CHANGES
    - NEW VEHICLE
      - THIOKOL MOTOR DATA FOR TUG APPLICATION

- CONFIGURATION



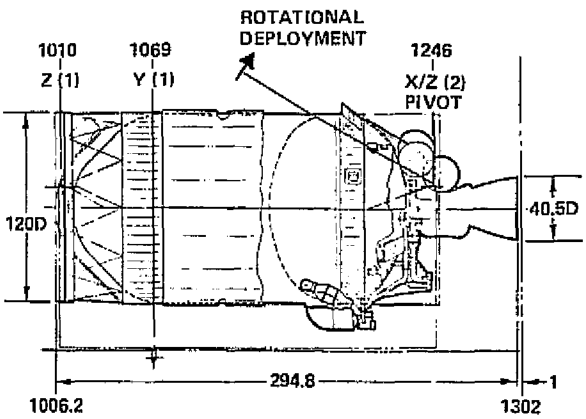
- CHARACTERISTICS

MAIN PROPULSION	3-STAGE SOLID	
MOTOR CONFIGURATION	A	B
STATUS	NEW	NEW
STAGE WT (LB.)	4,700	8,000
TOTAL PROP (LB)	4,200	7,200
USABLE PROP. (LB)	4,100	7,060
THRUST (LB)	VARIES	VARIES
I_{sp} (SEC)	290.7	291
ϵ	5/1	5/1
BURN TIME (SEC)	85	90
ACPS	N_2H_4	
MASS PROPERTIES	W (LB)	XCG (STA)
• VEHICLE: W_F (B/O)	3,570	—
W_I (SEP'N)	21,690	—
• SUPPORT STRUCTURE	2,200	—
• SUPPORTED: ASCENT	23,890	1202.19
ABORT	23,890	1202.19
+ MIN. S/C	715	1057.8
+ BALLAST	3,700	599.0
PERFORMANCE (LB)	4,400	

Figure 7-3. Reference Configuration II — Burner II IUS

- BASIS
  - BASELINE
    - NASA CR-134487, "CENTAUR/SHUTTLE INTEGRATION STUDY"
  - CHANGES
    - FUEL TANK ΔL = -78 IN.
    - OXIDIZER OFF-LOAD = 10,885 LB

- CONFIGURATION

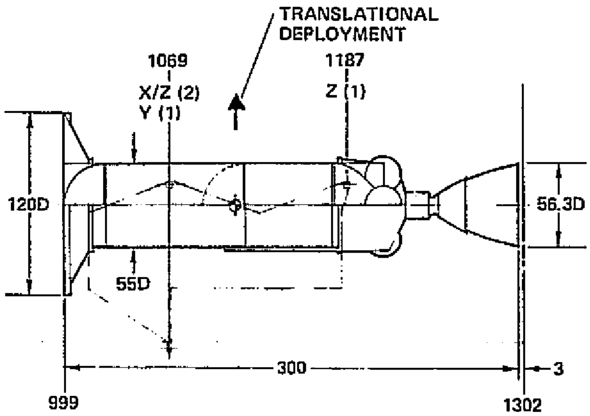


- CHARACTERISTICS

MAIN PROPULSION	CRYOGENIC	
• ENGINE = T (LB)	30,000	
ISP (SEC)	445	
ϵ	57	
MR (O/F)	5.0	
• OXIDIZER =	LO_2	
DENSITY (PCF)	68.67	
TOTAL (LB)	14,565.	
USABLE (LB)	14,032.	
• FUEL	LH_2	
DENSITY (PCF)	4.29	
TOTAL (LB)	3,204.	
USABLE (LB)	2,807.	
ACPS	H_2O_2	
MASS PROPERTIES	W (LB)	XCG (STA)
• VEHICLE = W_F (B/O)	5,245	—
W_I (SEP'N)	22,561	—
• SUPPORT STRUCTURE	3,428	—
• SUPPORTED = ASCENT	25,989	1169.4
ABORT	8,644	1137.6
PERFORMANCE (LB)	4,919	

Figure 7-4. Reference Configuration III — Centaur IUS

- BASIS
  - BASELINE
    - NASA CR-121122 "DELTA/SHUTTLE INTEGRATION STUDY"
  - CHANGES
    - FUEL TANK ΔL: +38.9 IN.
    - OXID TANK ΔL: +46.1 IN.
    - MR: 1.6 → 1.7
    - AVIONICS MODULE: 120 IN. DIA
- CONFIGURATION

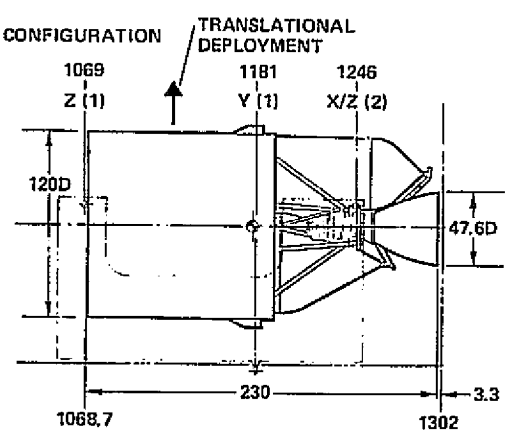


- CHARACTERISTICS

MAIN PROPULSION	STORABLE	
• ENGINE = T (LB)	9,850	
ISP (SEC)	304	
ε	43	
MR (O/F)	1.7	
• OXIDIZER=	N_2O_4	
DENSITY (PCF)	90.14	
TOTAL (LB)	11,837.	
USABLE (LB)	11,774.	
• FUEL	UDMH + N_2H_4	
DENSITY (PCF)	56.38	
TOTAL (LB)	6,963	
USABLE (LB)	6,926	
ACPS	N_2H_4	
MASS PROPERTIES	W(LB)	XCG (STA)
• VEHICLE = W_F (B/O)	2,230	—
W_I (SEP'N)	21,020	—
• SUPPORT STRUCTURE	1,316	—
• SUPPORTED = ASCENT	22,336	1112.65
ABORT	3,636	
PERFORMANCE (LB)	3,515	

Figure 7-5. Reference Configuration IV — Delta IUS

- BASIS
  - BASELINE
    - NASA CR-121135, "TRANSTAGE/SHUTTLE INTEGRATION STUDY"
  - CHANGES
    - MMC MCR-73-103
      - ΔL: + 52.3 IN.
      - Δ USABLE PROP. = +8638 LB.
      - NO P.U.
- CONFIGURATION



- CHARACTERISTICS

MAIN PROPULSION	STORABLE	
• ENGINE = T (LB)	16,000.	
ISP (SEC)	302.	
ε	40.	
MR (O/F)	1.99	
• OXIDIZER=	N_2O_4	
DENSITY (PCF)	89.69	
TOTAL (LB)	21,387	
USABLE (LB)	21,333	
• FUEL	UDMH + N_2H_4	
DENSITY (PCF)	56.15	
TOTAL (LB)	10,693	
USABLE (LB)	10,667	
ACPS	N_2H_4	
MASS PROPERTIES	W(LB)	XCG (STA)
• VEHICLE = W_F (B/O)	4,532	—
W_I (SEP'N)	36,660	—
• SUPPORT STRUCTURE	3,000	—
• SUPPORTED = ASCENT	39,660	1177.4
ABORT	7,606	
PERFORMANCE (LB)	4,980	

Figure 7-6. Reference Configuration V — Transtage IUS

7.2 INTERFACE COMPARISON

Comparisons of IUS vehicle characteristics and Orbiter interface requirements with those for Tug are documented in this section. Once again, since comparative evaluation was this tasks objective, English units only have been used in the following figures.

Important geometric, propulsion system, mass property, and performance characteristics for the five IUS candidates are arranged for comparison with the corresponding Space Tug characteristics in Figure 7-7. The Tug is physically larger (both in diameter and length) than any of the IUS vehicle candidates and has a comparatively higher performance capability. The Tug configuration is sized for a 3500 lb (1590 kg) synchronous equatorial payload retrieval mission. All IUS candidates except Centaur have a main propulsion system different than Tug and an attitude control propulsion system similar to Tug. Vehicle burnout weights, W_F, (vehicle dry weight plus nominal residuals) and Orbiter separation weights, W_I, (fully tanked with consumables, no peripheral equipment) are presented in Figure 7-7.

7.2.1 STRUCTURAL SUPPORT. There are two key issues in assessing IUS/Tug transition impacts on the structural interface:

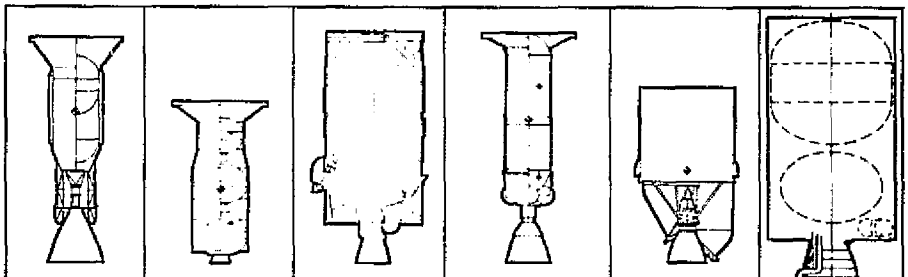
a. Do Tug and the various IUS candidates prefer the same support locations?

b. If not, does independent choice of support locations result in any transition incompatibility or constraint?

Figure 7-8 provides a graphic answer to the first issue: Although all IUS candidates use four-point statically determinate systems, each vehicle nevertheless prefers a unique set of support locations. The support locations shown for each IUS vehicle were either taken directly from existing documentation or selected from current Orbiter support nearest previously specified locations (Orbiter support locations were revised after some of the IUS/Shuttle Integration studies were completed).

When significant vehicle stretch (Delta) or CG shift (Agena, due to nozzle extension) was required, the original support arrangement characteristics (Y station relative to CG; X/Z support aft or forward) were retained and new locations selected from among the current Orbiter support locations.

Support reactions were computed for each vehicle using the latest ascent linear accelerations from MSFC PF-02-75-31. Angular accelerations were not included, and descent reactions were not computed for lack of inertia and post-dump CG data. All IUS vehicles exhibited support reactions within Orbiter capability for the cases considered.



	AGENA	BURNER II	CENTAUR	DELTA	TRANSTAGE	TUG
CONFIGURATION						
DIA (IN.)	60.0	69.0	120.0	55.0	120.0	176.0
LENGTH (IN.)	293.0	210.0	294.8	300.0	230.0	360.0
FWD STA (X_o)	1003.0	1089.0	1006.2	999.0	1068.7	936.0
DEPLOYMENT	TRANSLATE	TRANSLATE	ROTATE	TRANSLATE	TRANSLATE	ROTATE
MAIN PROPULSION	STORABLE	SOLID	CRYOGENIC	STORABLE	STORABLE	CRYOGENIC
OXIDIZER	HDA	–	LO_2	N_2O_4	N_2O_4	LO_2
USABLE (LB)	9,806.0	–	14,032.0	11,774.0	21,333.0	42,761.0
FUEL	MMH	4,100 (1)	LH_2	UDMH + N_2H_4	UDMH + N_2H_4	LH_2
USABLE (LB)	4,830.0	7,060 (2)	2,807.0	6,926.0	10,667.0	7,127.0
ENGINE T (LB)	16,000.0	VARIES	30,000.0	9,850.0	16,000.0	15,000.0
I_{SP} (SEC)	321.0	291.0	445.0	304.0	302.0	456.5
ACPS	N_2H_4	N_2H_4	H_2O_2	N_2H_4	N_2H_4	N_2H_4
WEIGHTS (LB)						
VEHICLE: W_F	1,500.0	3,570.0	5,245.0	2,230.0	4,632.0	5,766.0
W_I	16,432.0	21,690.0	22,561.0	21,020.0	36,660.0	56,779.0
SUPPORTED						
ASCENT	17,727.0	23,890.0	25,989.0	22,376.0	39,660.0	57,487.0
ABORT	3,091.0	23,890.0	8,644.0	3,636.0	7,606.0	6,926.0
PERFORMANCE (LB)	3,566.0	4,400.0	4,919.0	3,515.0	4,980.0	17,200.0

Figure 7-7. Comparison I — Vehicle Characteristics

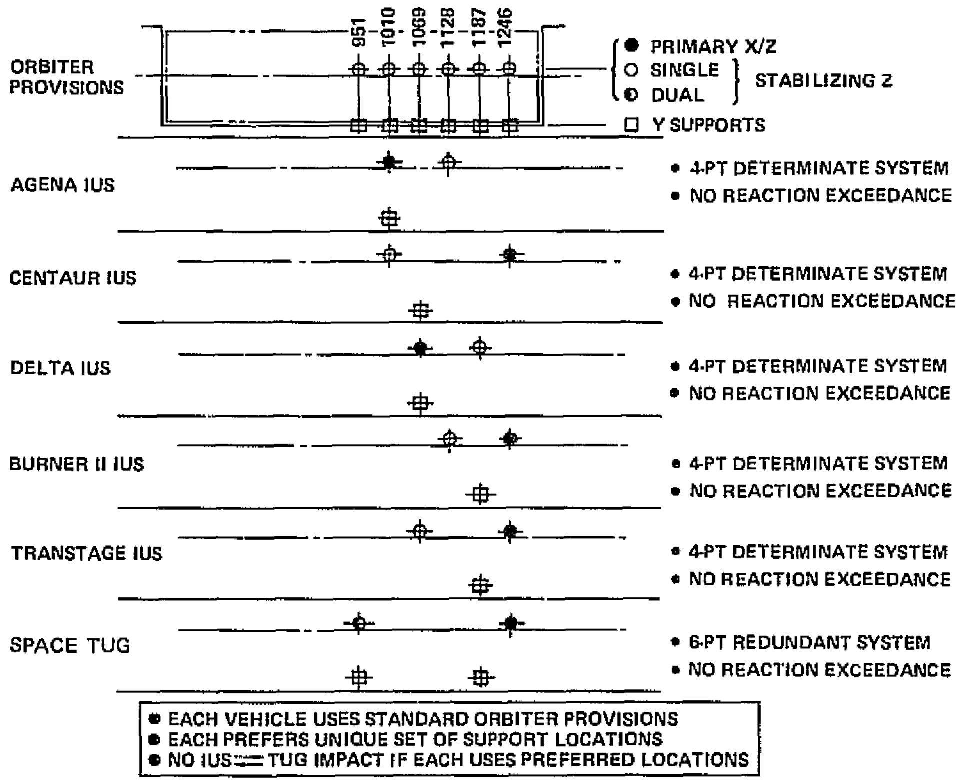


Figure 7-8. Comparison II — Structural Interface

With respect to the second issue, despite the multiplicity of preferred support systems, there is no transition impact. This results from the fact that the structural attachment provisions (bridge beams and keel fittings) are provided by the Orbiter as bolt-on, mission-peculiar equipment. Therefore, each vehicle can use its preferred support arrangement subject to only one constraint: support locations must be selected from among these currently provided by the Orbiter.

7.2.2 DEPLOYMENT MECHANISMS. The operational comparison offering the best potential visibility into IUS/Tug mechanism compatibility involves the functions performed during Tug or IUS deployment. Figure 7-9 shows the seven basic operations that provide deployment for all six vehicles. The following similarities are evident:

a. Four steps are the same for all upper stages.

b. Of these four, three involve Orbiter equipment/operations. While these Orbiter-provided services may not be identical for each stage, the versatility provided in RMS control capability and Orbiter maneuvering flexibility provides inherent compatibility with a wide variety of operations.

c. The fourth step, "disconnect umbilicals," is performed by stage-provided peripheral equipment (pallet, cradle, deployment adapter), which causes no Orbiter accommodations impact.

d. The remaining three functions (rotation, cradle release, and latch release) are also performed by stage-peculiar peripheral equipment mechanisms, which have no impact on Orbiter interface accommodations.

The conclusion reached from this comparison is that no significant mechanical interface differences exist between IUS and Tug.

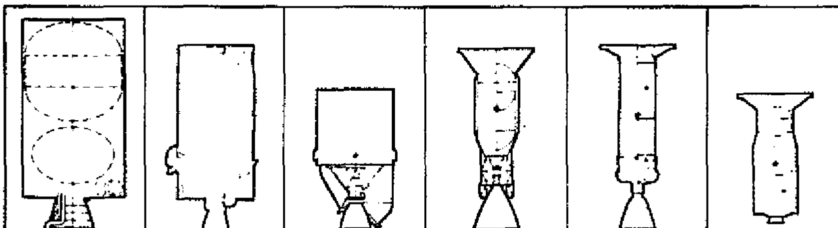
7.2.3 FLUID SERVICES. Figure 7-10 compares interface and service line requirements for Tug and five potential IUS configurations. The Centaur IUS requirements are quite similar to Tug but with generally smaller fill, drain, dump and vent line requirements because of the smaller vehicle size. Transtage and Agena IUS vehicles have reduced interface requirements because off-pad loading of all fluids is assumed. The Burner II IUS has minimal fluid interface requirements since it is a multiple stage solid propellant vehicle.

Because of the quantity and diameter variations between Tug and storable IUS fluid interface requirements, it was concluded that transistion between these two vehicle types is not accomplised without some difficulty. At best, separate fluid line kits would be required in the Orbiter. Removal of the storable IUS set and replacement with cryogenic Tug service lines could require considerable ground operations time.

	ROTATE FOR DEPLOYMENT	ATTACH RMS	DISCONNECT UMBILICALS	OPEN CRADLE TRANSLATE FORWARD	RELEASE SUPPORT LATCHES	DEPLOY WITH RMS	BACK AWAY ORBITER
AGENA		✓	✓		✓	✓	✓
BURNER		✓	✓		✓	✓	✓
CENTAUR	✓	✓	✓		✓	✓	✓
DELTA		✓	✓		✓	✓	✓
TRANSTAGE		✓	✓	✓		✓	✓
TUG	✓	✓	✓		✓	✓	✓

NO SIGNIFICANT DIFFERENCE BETWEEN IUS CANDIDATES OR TUG

Figure 7-9. Comparison III — Mechanical Interface Deployment Methods

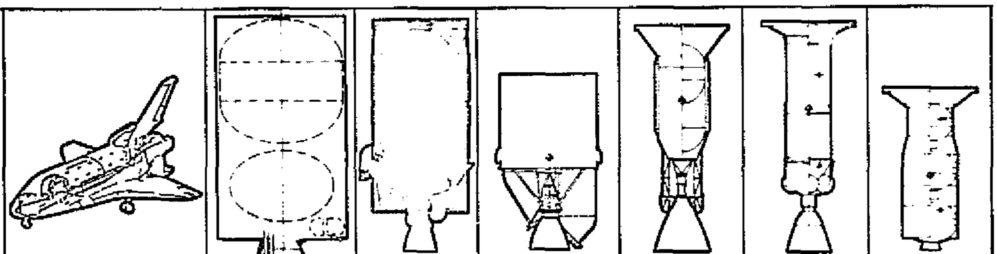


	TUG	CENTAUR	TRANSTAGE	AGENA	DELTA	BURNER II
OXIDIZER, 1307 & T-O PANELS						
FILL & DRAIN / DUMP	4.0	3.0	3.0 (DUMP)	3.0 (DUMP)	1.5(3)	
TOPPING	0.75	0.75				
LEAKAGE VENT	0.75	0.75				
INERT GAS FILL	0.375 (He)	0.375 (He)			0.25 (He)	
RCS RELIEF	–	0.5 (H_2O_2)				0.25 (H_2O_2)(1)
RTG WATER IN	0.5	0.5	0.5	0.5	0.5	0.5
OUT	0.5	0.5	0.5	0.5	0.5	0.5
RTG STEAM VENT(2)	3.0	3.0	3.0	3.0	3.0	3.0
TANK VENT	2.0(1)	1.0(1)			0.25	
OXIDIZER OVERFLOW					0.5	
FUEL, 1307 & T-O PANELS						
FILL & DRAIN / DUMP / TOPPING	6.0	3.5	3.0 (DUMP)	3.0 (DUMP)	1.5(3)	
TANK VENT	3.0	1.5			0.25	
TANK RELIEF	2.5(2)	1.5(2)				
LEAKAGE VENT	0.75	0.75				
RCS RELIEF	0.6 (N_2H_4)	–				
BULKHEAD VENT		1.0				
INERT GAS FILL					0.25 (N_2)	
FUEL OVERFLOW					0.5	

(1) EXIT THROUGH MID-BODY. NO 1307 OR T-O INTERFACE
(2) NO T-O INTERFACE
(3) FOR 300 SECOND SEQUENTIAL DUMP

Figure 7-10. Comparison IV — Fluid Interfaces

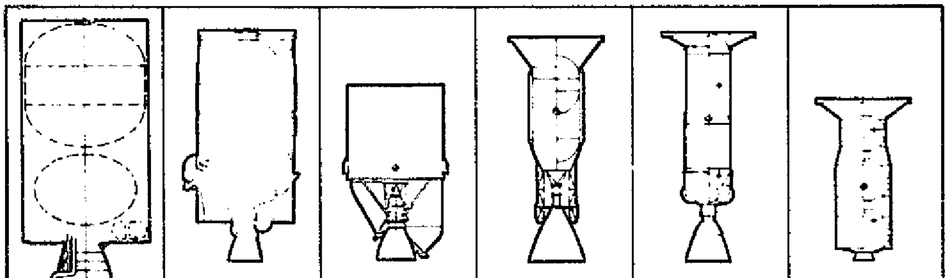
7.2.4 PRELAUNCH CONDITIONING. A review was made of the prelaunch conditioning requirements for both the baseline Space Tug and the Interim Upper Stage (IUS) candidates, and the results compared with the Space Shuttle Orbiter capability, as shown in Figure 7-11. The requirements data for the IUS candidate stages were obtained from the final reports of the Shuttle Integration studies sponsored by NASA/LeRC in 1973. The Orbiter provides a gaseous nitrogen (GN_2) purge in the payload bay before launch for space craft and Tug or IUS environmental conditioning. The GN_2 provides a low humidity (0-9 grain H_2O/lb N_2) atmosphere with flow between 0 and 364 lb (165 kg) GN_2/minute at temperatures between 45 and 120F (7 and 40C). An analysis of Tug-mounted spacecraft conditioning requirements indicates a prelaunch temperature between 59 and 69F (15 and 21C) is necessary for some spacecraft, which established the limits for Tug. The IUS system specification indicates IUS-mounted spacecraft will generally require prelaunch temperatures between 50 and 70F (10 and 21C). All of the propulsion stages generally are compatible with thes prelaunch temperature requirements. Purge flow rate requirements were specified only for the cryogenic stages and fall within the capability of the Orbiter purge. None of the projected Tug NASA payloads had any requirement for a high humidity prelaunch environment. Discussions with DOD personnel however, indicate possible spacecraft prelaunch humidity requirements as high as 88 grains H_2O/lb GN_2. All IUS stages appear to be compatible with a high humidity environment; however, the Orbiter design is not capable of providing humidity greater than 1 grain H_2O/lb GN_2. The Tug is compatible with Orbiter capability.



	ORBITER CAPABILITY	TUG	CENTAUR	TRANSTAGE	AGENA	DELTA	BURNER II
GN_2 FLOW (LB/MIN)	0-364	140-364	314-364	NS	NS	NS	NS
GN_2 TEMP (F)	45-120	59-69 (P/L REQ)	55-75	>65	65-85	55-90	60-70
GN_2 HUMIDITY (GR/LB)	0-1	0-1	0-88	ANY	NS	NS	0-100

Figure 7-11. Comparison V — Environmental Interface Prelaunch Conditioning Requirements

7.2.5 AVIONIC INTERFACES. A comparison of the avionics interface requirements of the various candidate IUS vehicles with respect to those of the Tug was accomplished to determine which interface requirements were compatible and to identify areas of incompatibility where interface optimization may be possible. A summary of this comparison is presented in Figure 7-12. This data was derived by updating data from previously published expendable upper stage vehicle studies (current IUS study data was not available) to conform with current NASA and DOD requirements and to utilize Orbiter support capability.



	TUG	CENTAUR	TRANSTAGE	AGENA	DELTA	BURNER II
ORBITER SUPPORT	PDI, PSP, MDM	S.A. TUG	S.A. TUG	S.A. TUG	S.A. TUG	S.A. TUG
EQUIPMENT	PI, GPC, CRT					
ORBITER STATIONS	MSS, PHS	MSS, PHS	MSS	MSS	MSS	MSS
ORBITER SUPPORT	≈ 5.6K	≈ 6.K	YES	≈ 8.6K	(TBD)	YES
SOFTWARE (KOPS)	(20 K OPTS)	(20 KOPTS)	N.D.	(80 KOPTS)	(TBD)	N.D.
TLM	14.4 KBPS	16.2 KBPS	N.D.	4 KBPS	(13.89 KBPS)	< 8 KBPS
P/L UNIQUE (D&C)	YES	YES	YES	YES	YES	YES
POWER	100W	S.A. TUG	40	355W	EST ≡ TUG	N.D.
WT	18 LB.	S.A. TUG	35 LB	74 LB	35 LB	EST ≈ 35 LB
PANELS (AREA)	3 (100 IN.^{2})	3 (100 IN.^{2})	19 (230 IN^2)	2 (709 IN.^{2})	N.D.	(230 IN.^{2})
P/L S/W (K WDS)	≈ 10.4K	≈ 10K	4 KWDS	≈ 7.4 KWDS	200K	N.D.
C&W FUNCTIONS	<18	<18	12 + 2 BAT	14 + BAT	13 + 3 BAT	11 + 3 BAT
FORWARD I/F (596)	16	80 + 2 COAX	≈ 100 + 8 COAX	88	≈ 102	62
ORBITER POWER	2340W	500W	605W	N.D.	2,240W	800W

Figure 7-12. Comparison VI — Avionics

This data summary indicates that all IUS candidate vehicles will use basically the same Orbiter support equipment as the Tug, and that present Orbiter capabilities for payload power and cabling interfaces are sufficient. For example, Tug plus IUS candidate vehicle required:

a. Orbiter located avionic equipment capable of communicating with the IUS/Tug vehicle in both attached and detached modes.

b. Orbiter-located data-processing capability for monitoring Tug/IUS telemetry data.

c. A man-machine interface (CRT and keyboard) to allow crew control and monitor capability.

d. Various crew control panels to effect and monitor IUS commands and status.

These requirements are currently satisfied (for Tug and at least one IUS candidate) by the Orbiter payload support avionics group consisting of the PDI, PSP, MDM, PI, GPC, and the aft crew cabin (MSS) CRT and keyboard. In addition, each IUS candidate requires caution and warning monitoring capability (for less than 20 signals).

The degree of Orbiter-to-Tug/IUS interface similarity is indicated in Figure 7-13, which shows the avionics interface for the Centaur IUS. In a manner similar to the recommended Tug interface concept, control and monitoring of the IUS vehicle (by Orbiter) occurs through digital uplink (2 kbps) and downlink (16 kbps) routed through the payload signal processor (NASA) or payload interrogator (DOD missions). Hardwired warning functions from the IUS are connected to the Orbiter C&W electronics unit, and IUS pallet monitoring occurs through a redundant 16 kbps multiplexed downlink to the Orbiter payload data interleaver.

Unlike the Tug/Orbiter interface, however, Centaur IUS pallet control is accomplished through a redundant set of 23 discrete lines (from the two Orbiter payload MDM units) to two pallet control sequencer units. The pallet control sequencer is actually the same unit as the IUS Centaur flight sequence control unit and was selected (over a command decoder as in the Tug deployment adapter) because of the lower initial development and qualification costs, even though the physical IUS/Orbiter interface size increases (46 additional hardwires). It should also be noted that the IUS candidate employs the Orbiter GPC computer and aft cabin equipment (CRT, keyboard, and IUS-unique control panels) in much the same manner as Tug.

Because of the functional commonality of payload support hardware required by both Tug and IUS candidate vehicles, the greatest avionics interface impact will probably result from a transition from IUS to Tug operations. This will concern the Orbiter support software and associated payload-unique software programs that operate within the Orbiter's general-purpose computer (GPC) system. Although different software support packages will be required for each candidate IUS vehicle, it is felt that the software interfaces associated with the Centaur-to-Tug transition will be less severe than for the other IUS candidates. This is because both Tug and Centaur are cryogenic stages and thus similar programs will be required for control, monitoring, checkout, and safety monitoring operations.

7.2.6 <u>COMPARISON OF INTERFACE SAFETY</u>. The published data on each of the candidate Tug/IUS vehicles was reviewed to determine their potential impact on interface safety. The interfaces having the greatest potential impact on Space Shuttle safety are considered to be those interfaces associated with Tug/IUS propellants.

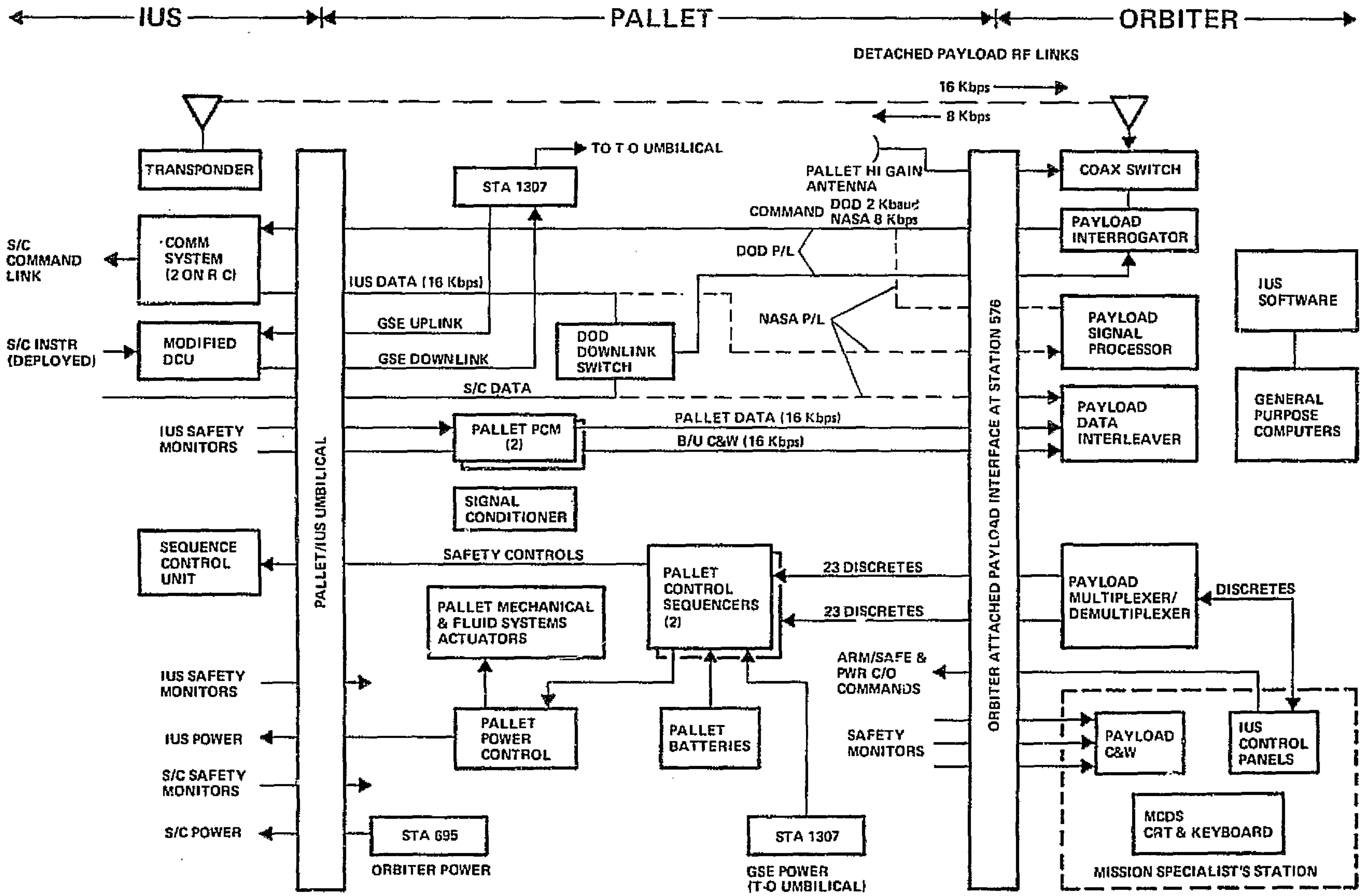
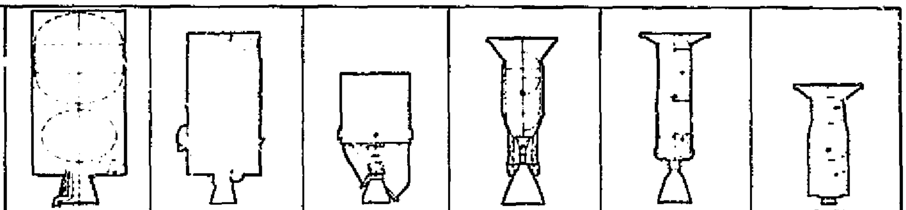


Figure 7-13. Centaur — IUS Interface Implementation

The principal propellant safety requirements/considerations are summarized in Figure 7-14. A check mark in the figure indicates that the candidate vehicle is compliant with the safety requirement/consideration. Where the candidate is not considered to be compliant, an indication is made as to which vehicle feature, or absence thereof, causes it to be noncompliant. The only instance where complaince is unclear is the case of the vent capability for the Transtage. Some documentation indicates vent capability, while other documentation indicates no vent capability.



PROPELLANT SAFETY REQUIREMENTS/ CONSIDERATIONS	TUG	CENTAUR	TRANSTAGE	AGENA	DELTA	BURNER II
PAD ABORT PROPELLANT DUMP CAPABILITY	✓	✓	✓	✓	✓	NO DUMP CAPABILITY
INFLIGHT ABORT DUMP CAPABILITY	✓	✓	✓	✓	✓	NO INFLIGHT DUMP POTENTIAL, ABORT LANDING PROBLEM
ISOLATION VALVES (PRECLUDE LEAKS IN LINES/FITTINGS)	✓	✓	✓	✓	NONE INDICATED	NOT APPLICABLE
PROPELLANT VENT CAPABILITY	✓	✓	?	✓	✓	NOT APPLICABLE
AVOIDANCE OF COMMON PRESSURE SOURCE FOR HYPERGOLICS	✓	✓	COMMON PRESSURE SOURCE	COMMON PRESSURE SOURCE	COMMON PRESSURE SOURCE	✓
ORBITER SURFACE CONTAMINATION AVOIDANCE (ABORT DUMP)	✓	✓	POTENTIAL CONTAMINATION	POTENTIAL CONTAMINATION	POTENTIAL CONTAMINATION	NOT APPLICABLE
AVOIDANCE OF COMMON BULKHEADS	✓	DUAL-REDUNDANT BULKHEADS; EXTERNALLY VENTED	✓	SINGLE BULKHEAD	SINGLE BULKHEAD	NOT APPLICABLE
AVOIDANCE OF PRESSURE-STABILIZED STRUCTURE	PRESSURE STAB. REQUIRED DURING UP FLT/DN FLT	PRESSURE STABILIZED STRUCTURE	PRESSURE STAB. REQUIRED DURING UP FLT/DN FLT	PRESSURE STAB. REQUIRED DURING UP FLT/DN FLT	PRESSURE STAB. REQUIRED DURING UP FLT/DN FLT	✓

Figure 7-14. Comparison VII — Safety Interface

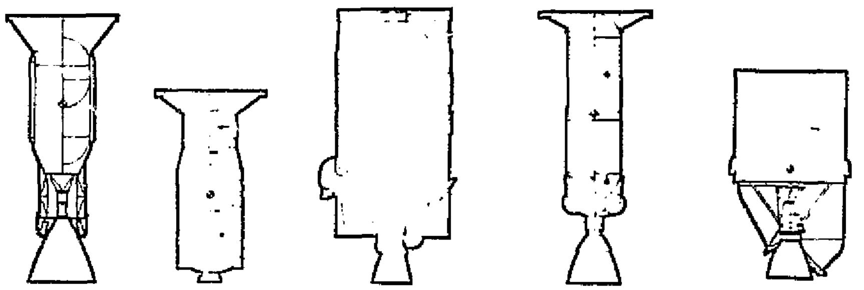
While the Centaur is the only vehicle classified as a pressure stabilized structure, it is in fact the case that all candidates that use liquid propellants require pressure integrity. The structural integrity of these vehicles is dependent on maintaining pressurized propellant tanks for the increased loads that occur during Space Shuttle boost. During return flights, or during an aborted flight, pressure integrity must also be maintained to preclude tank implosion.

7.3 IUS/TUG PRELIMINARY ·TERFACE OBSERVATIONS

In Section 7.1 interface data for .ne five expendable interim upper stage (IUS) candidates currently being studied was obtained by updating previously published information to reflect current Orbiter payload accommodations and USAF performance and

configuration requirements. Each interface area (structural, mechanical) was investigated in Section 7.2 to determine compatibility with Tug requirements and the Orbiter impact due to exchanging IUS candidates for Space Tug.

The five candidate vehicles and the interface comparison summary results obtained from this work are shown in Figure 7-15. Find numbers for each IUS configuration are used for identification in the Tug comparison column. The structural and environmental interface comparison for IUS/Tug showed full compatibility due to the flexibility of Orbiter accommodations; i.e., multiple support locations and wide range or prelaunch conditioning control. Mechanical interfaces were also compatible, because all unique IUS requirements are satisified by cargo bay-mounted peripheral equipment in a manner similar to Tug. The two remaining functional interfaces, fluids and avionics, are generally compatible (with slight differences) for Tug and the Centaur cryogenic IUS and are incompatible with Tug for the storable and solid propellant IUS candidates.



INTERFACE	TUG COMPARISON	ORBITER IMPACT
STRUCTURAL	ALL COMPATIBLE	NONE
MECHANICAL	ALL COMPATIBLE	NONE
FLUID	3 COMPATIBLE	NONE
	2 WITHIN REQTS	REMOVE FLUID SERVICE KITS
	1 4 5 INCOMPATIBLE	EXCHANGE FLUID SERVICE KITS
ENVIRONMENTAL	ALL COMPATIBLE	NONE
AVIONICS	3 SIMILAR	MINOR S/W & PANEL MODS
	1 2 4 5 INCOMPATIBLE	MAJOR S/W & PANEL CHANGES
SAFETY	3 COMPATIBLE	NONE
	1 4 5 INCOMPATIBLE	EXCHANGE FLUID SERVICE KITS
	2 NO ABORT DUMP	POSSIBLE LANDING RESTRICTIONS
OPERATIONS	3 COMPATIBLE	NONE
	OTHERS DIFFERENT	LOADING, ABORT, SAFING

Figure 7-15. IUS/Tug Interface Comparison Summary

The safety and operations interfaces have Tug comparisons and Orbiter impacts similar to the fluid and avionics functional interfaces. The Tug and Centaur IUS are compatible since they use the same cryogenic propellants. Conversely, the dissimilarity of storable and solid IUS propellants from Tug propellants causes major differences in safety implementation procedures and Orbiter ground and flight operations.

These functional and operational interface incompatibilities can be readily accommodated by kit implementation of fluid service lines and cargo bay electrical umbilicals and by revising interface monitor and control software and control panels. The optimized interface alternative to the kit concept is considered unacceptable because of the design compromises that must be made to implement this approach.

The IUS/Tug transistion investigation performed by the Interface Compatibility Study has verified the Orbiter approach toward satisfying a variety of payload fluid/electrical and operational interface requirements: payload-peculiar service kits.

SECTION 8

IMPLICATIONS FOR RESEARCH

Interface-related areas that would benefit from additional technical effort have been identified during performance of the Space Tug/Shuttle Interface Compatibility Study. These technical activities have been separated into four categories: identification of technology drivers, additional analyses of critical interface areas, predevelopment breadboard or prototype design activity to reduce risk and program costs, and recommended supporting research and technology programs.

8.1 TECHNOLOGY DRIVERS

This category pertains to new technology developments required to effect the recommended interface concept. Since all study recommendations for Tug/Orbiter interface implementation use current technology and/or available off-the-shelf hardware, no technology drivers exist for peripheral equipment development.

8.2 TECHNICAL ANALYSES

Areas listed below are recommended for expanded interface analyses. All these areas were investigated during the interface compatibility study, and additional analyses beyond the scope of contracted study effort are required for problem solution or interface definition/verification. In conjunction with the needed analyses, many of these items are also candidates for subsequent predevelopment work as indicated in Section 8.3.

a. Structural Dynamics. The most significant Tug support issue resulting from study work was dynamic response characteristics (deflection and natural frequency). Very simplified Tug/payload Orbiter modeling techniques and preliminary forcing stimuli have been used in the dynamic response studies performed to date. More rigorous analyses using up-to-date Orbiter data are required to better determine Orbiter payload effects.

b. RMS Software Control. Study work established feasibility of Tug deployment/retrieval with RMS by selecting a representative operating mode. Other suitable RMS motion combinations should be evaluated to determine optimum RMS use for Tug. RMS joint (wrist, elbow, shoulder) angle geometry and force characteristics should then be quantified for control software development.

c. Tug Monitor and Control Software. All Tug/Orbiter operational interfaces (status verification, deployment, retrieval, abort) should be analyzed to develop/design the required software. This work includes determination of Tug/Orbiter software interfaces and allocation of software responsibility.

d. Tug Caution and Warning Software. Using philosophy and implementation tools developed during interface study investigations, software should be designed for all Tug caution and warning functions. This work includes determination of software availability, critical message logic (function of mission phase), and development of CRT display message hierarchy. Additionally, CRT corrective action/anomaly identification display format for each caution and warning function should be identified.

e. Avionics Ground Interface with LPS. Tug/Orbiter interface avionics definition should be expanded to include its functional prelaunch ground interface with the KSC launch processing system. Formats, bit rates, signal characteristics, and Orbiter software impact (if any) due to prelaunch LPS integration should be determined.

8.3 PREDEVELOPMENT ACTIVITY

To demonstrate feasibility of the preceding technical analyses results, simulation activity with prototype software and hardware should be performed. This predevelopment work will verify analytical solutions and/or identify interface problems early enough to reduce risk and program costs. Three areas have been identified that offer very fruitful ground for simulation-demonstration work.

a. Remote Manipulation System (RMS) control for the deployment, recapture and insertion into the cargo bay, including development and simulation of:

   Control devices (joy stick, rate trim wheel, etc.).

   Movement programs.

   Boundary and interference prevention programs.

   Operator viewing aids (targets, TV cameras).

   Man-machine interface verification for Tug operations.

b. Prototype development and demonstration of the following Tug deployment adapter (D/A) mechanisms:

   Deployment rotation redundant actuators.

   Umbilical panels.

   D/A Tug latches.

   D/A Tug insertion alignment aids.

c. Integration and test of Tug crew compartment monitor and control equipment with D/A peripheral equipment and selected Tug prototype systems and flight operations:

   Propellant abort dump.

   Deployment (peripheral equipment functions).

Communications (RF and hardwire).

Tug/Orbiter monitor & control software.

Caution and warning.

Tug/Orbiter computer support.

8.4 SUPPORTING RESEARCH AND TECHNOLOGY

Several interesting research areas associated with Tug/Orbiter interface needs were identified during the study. They include applications problems that must be resolved, pure theoretical research, and investigation of a current expanding technology for possible space application.

a. Concentrated Load Introduction Into Graphite Epoxy Structure. The deployment adapter (and Tug shell) use titanium fittings to accept Orbiter attachment loads. Efficient transmission of these large (100,000 pounds) concentrated loads to thin wall (0.12 inch) graphite epoxy sandwich facings must be developed and demonstrated.

b. Graphite Epoxy Structure Grounding. To preclude static charge buildup and subsequent discharge to Tug tank structure and Orbiter, a technique must be developed to make the graphite epoxy structure surface electrically conductive and connectable to the tank.

c. LH_2-LO_2 Engine Charging Experiment. Little or no data is available on LH_2/LO_2 engine charging at high altitudes. It is recommended that a Centaur vehicle be instrumented to collect engine charging, photoelectric and plasma charging data in the region from low earth altitude (160 n.mi.) to synchronous altitude. A Titan-Centaur launch of a Helios satellite (TC-5), scheduled for late 1975, will have excess performance capability that might be used for Tug development purposes.

d. Low-Power, High-Reliability Actuators. The current Space Tug and deployment adapter concepts employ nonlatching valves for control of fluids and gases. Because these valves are of the nonlatching type (current mechanical latching valves exhibit low reliability), relatively large amounts of steady-state electrical power are required of the Tug or Orbiter systems for their operation. Techniques other than mechanical latching (residual magnetic flux) for power reduction should be evaluated. Development work should include:

Optimization of materials with respect to electromagnetic properties of valve components.

Vibration and environmental testing to determine if launch vehicle environment would degrade materials.

Incorporation of built-in sense logic, self-test logic, and override logic required for Tug applications.

e. Optical Data Link Techniques. During the time-period in which the Tug will become operational, data-link techniques employing optical components will be available and offer potential Orbiter/Tug interface communication benefits in terms of lower weight and power requirements, increased electrical signal isolation, and higher operating speeds than conventional interface components. Analysis and development are required, however, to determine reliability and performance of optical data link techniques in space environment applications.